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Digital simulation of sheet erosion

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by

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CHAPTER I. INTRODUCTION

Soil erosion is a major problem today. Bennett (1939) estimated that approximately 3 billion tons of soil was washed out of the fields and pastures in the United States in 1939. Williams (1967) estimated 4 billion tons in 1967.

Not only is soil lost, but that carried by water contains higher proportions of plant nutrients, organic matter, and finer materials than are found in the original soil. The nutrient carrying sediments polute streams and rivers. Reservoirs and ponds built for flood control, water supply, and recreation are reduced in capacity and in water quality.

The severity of the erosion problem is gradually being recognized by the nonagricultural public sector which is demanding control through legislative actions. Accurate estimates of the pattern of sediment movement from the fields into the larger streams are essential for the effective administration of legislative controls.

Objectives

The primary objective of this study is to develop a digital model of soil erosion by water. Specifically, this will involve:

(a) The development of a digital model to simulate the process of sheet erosion by water.

(b) The superimposition of the digital erosion model on a working mathematical watershed model.

(c) The application of the model to a small test watershed in order to evaluate its feasibility.

CHAPTER II. REVIEW OF LITERATURE

Sheet erosion is the product of the raindrop impact and overland flow. The distinctive actions of the raindrops and overland flow derive from the different directions in which their forces are applied to the land surface. Raindrops strike the soil surface from nearly a vertical direction. The impact of raindrops breaks down soil aggregates and splashes soil particles into the air, thus producing soil detachments known as splash erosion.

When the rate of rainfall exceeds the intake capacities of the soil, water that is not absorbed where it falls moves over the land surface as overland flow. It gains speed as it moves downslope and it also dislodges and transports soils. This process by which water sets soil in motion is known as scour erosion. In this study splash and scour erosion will be jointly taken as sheet erosion. Furthermore, sheet erosion will be defined to include both sheet and rill erosion.

Splash Erosion

More than 20 years ago, Ellison (1947) defined soil erosion as a process of detachment and transportation of soil materials by erosive agents. For erosion by water, these agents are rainfall and runoff. He pointed out that each has a detaching and transporting capacity, and that these must be studied separately. He suggested an approach to erosion studies that would consider: (a) soil detachment by rainfall; (b) transport by rainfall; (c) detachment by runoff; and (d) transport by runoff as separate but interrelated phases of the process of soil erosion by water.

The terminology used by various investigators has not been consistently defined. Many investigators refer to soil splash loss as the amount of soil collected on soil traps after a given rainfall. Thus soil splash refers to the net amount of soil being translocated since the soil particles can move in and out of the soil traps. This concept of soil splash will be used in the following discussions. In addition, the term transport by rainfall will be used to describe the net amount of soil that is moved downslope toward the rill or channel system. Thus, on a flat, smooth slope the soil transport by rainfall is zero. Detachment by rainfall will be used to refer to the total amount of soil translocated. Detachment by rainfall then refers to the total amount of soil moving in and out of a given area.

Theoretically, the effect of rain splash is a function of the kinetic energy of raindrops. That is

$$\text{Soil splash} = f(KE) = f(M\ V_T^{\,2}) \qquad (2\text{-}1)$$

where KE is the kinetic energy, M is the mass of raindrops, and V_T is the terminal velocity or the velocity with which the raindrops strike the soil. Since for any precipitation duration, the mass is directly related to the accumulated depth, the theoretical kinetic energy may be calculated if the terminal velocities are known. Terminal velocities, however, vary with drop size and there is normally a spectrum of drop sizes in every storm (Mihara, 1951; Wischmeier and Smith, 1958). Furthermore, the energy transmitted by raindrops to the soil is influenced by many factors rendering the theoretical approach impractical for many field applications. Commenting on some of these factors, Ellison (1945) stated:

> In soil and water conservation, the principal interest lies in determining the energy of raindrops that strike the soil. This may be a different problem from that of calculating the total energy of rainfall. Some of the drops are intercepted by plant residues and stones on the surface of the soil, while others may be intercepted by growing vegetation. The vegetal canopy may change storms and this may complicate the problem of comparing the effect of one storm with those of another. Often without change in the canopy, different amounts of interception will occur with different storms if a high wind drives them at an angle with the vertical. The same canopy may intercept less than 50 per cent of the drops if they fall vertically. In drilled crops with open canopies, the direction of the wind may affect the impact of raindrops on the surface of the soil. If the wind blows across the rows, most of the drops may be intercepted, but if the wind blows parallel to the rows, only a small percentage of the drops may be intercepted.

Several investigators have attempted to relate the physical characteristics of rainfall to soil splash. Laws (1940) observed a 1,200 per cent increase in the erosion rate when he increased the drop size from 1 to 5 millimeters. Mihara

(1951) reported soil splash as directly proportional to kinetic energy. Bisal (1960) shows detachment proportional to the 1.4 power of the drop velocity. Ekern (1951) shows splash proportional to the kinetic energy when the amount of applied water is constant. Rose (1960) reports that detachment is more closely related to momentum per unit area and time of rain than to the kinetic energy. Free (1960) found that splash losses from sand varied as the 0.90 power of the drop energy but to the 1.5 power of the drop energy for a silt-loam soil.

Ellison (1945) conducted studies in the effects of raindrop impacts on soil erosion using artificial rainfall on Muskingum silt-loam soil. He suggested the following relation between the quantities of soil splashed and rainfall characteristics

$$E = K\, V^{4.33}\, d^{1.07}\, I^{0.65} \qquad (2\text{-}2)$$

where

E = soil intercepted during a 30-minute period in grams

V = velocity of drops in feet per second

I = intensity of rainfall in inches per hour

d = diameter of drops in millimeters

K = soil constant

The quantities of soil splashed by raindrops were found to be very sensitive to either drop size or drop velocity.

These quantities were also affected by rainfall intensity and surface slope. Ellison found that 75 per cent of the splashed soil moved downhill and 25 per cent moved uphill on a 10 per cent slope.

Ekern and Muckenhirn (1947) found 60 per cent downslope and 40 per cent upslope movement of splashed sand on a 10 per cent slope. They suggested the relation where the relative downslope movement by splash is approximately equal to 50 per cent plus the per cent slope. This differential movement by vertical raindrops is explained by the fact that the downhill splash travels further before recontacting the soil surface. This is particularly important on steep slopes (Mihara, 1951). Wind effects in the field, however, may upset this pattern. Studies from oriented pans exposed to natural rainfall in New York showed three times more soil losses from pans facing the direction of the storm as from pans facing the opposite direction (Free, 1952).

Using four types of soil, namely, Darwin silty loam, Cisne silt loam, Flanagan silt loam, and Hegener loamy sand, Bubenzer and Jones (1970) studied the effects of drop size and impact velocity on the detachment of soils under simulated rainfall. Multiple regression techniques were used to relate soil splash to the rainfall characteristics for each of the four soils. Rainfall intensity and kinetic energy were found to be the best predictors of soil splash.

They derived the equation of the form:

$$SS = a\ (i)^{s}(Ke)^{t} \tag{2-3}$$

where

SS = the amount of soil splash

i = rainfall intensity

Ke = kinetic energy

a = constant

s,t = constant exponents

The correlation coefficient obtained ranged from 0.92 for the Darwin silty clay to 0.96 for the Flanagan and Cisne silt loams. In each case, the correlation coefficient obtained for each of the separate soils was significantly better than the coefficient for all the soils combined. The prediction of soil splash for all soils was improved by adding a term containing the percentage clay to Equation (2-3).

An analysis of soil transportation by raindrop splash was made by Van Heerden (1967) using mass distribution curves. These curves were graphs showing the amounts of splashed soil received per unit area. They were determined experimentally by measuring the amounts of soil that splashed out of a source tray into collecting trays. With mass distribution curves, the loss or gain in splashed particles can be determined at any point within an area.

Since under normal field conditions neither the drop velocity nor the drop diameter can be conveniently measured, investigations were directed towards finding functional relationships among the drop velocity, drop diameter, and rainfall intensity. Wischmeier and Smith (1958) by partly utilizing published information developed the equation

$$E = 916 + 331 \log_{10} I \tag{2-4}$$

where

E = the kinetic energy in foot-tons per acre inch of rain

I = rainfall intensity in inches per hour

They obtained a good index of soil loss per storm with the product $E\ I_{30}$, where E is the total energy computed from Equation (2-4) and I_{30} is the maximum 30-minute intensity during the storm in inches per hour.

Mihara (1951) illustrated the relation between rainfall intensity and energy by the following equation

$$E = A\ I^{1.20} \tag{2-5}$$

where

E = kinetic energy

I = rainfall intensity

A = soil constant

Scour Erosion

No soil erosion relationships commonly used to date distinguish between the rainfall splash and the overland flow subprocesses. The most commonly used soil loss equation estimates the combined sheet and rill erosion. The Agricultural Research Service of the USDA developed the so-called universal soil loss equation (Wischmeier and Smith, 1965), which has the form

$$A = R\ K\ LS\ C\ P \qquad (2\text{-}6)$$

where

A = average annual soil loss in tons per acre

R = rainfall factor

K = soil erodibility factor

LS = length and steepness of slope factor

C = cropping and management factor

P = conservation practice factor

A soil loss equation similar in nature to Equation (6) which is much in use is the Musgrave's (1947) equation

$$E = I \left[\frac{R}{100}\right] \left[\frac{S}{10}\right]^{1.35} \left[\frac{L}{72.6}\right]^{0.35} \left[\frac{P}{1.25}\right]^{1.75} \qquad (2\text{-}7)$$

where

E = sheet and rill erosion in inches per year

I = erosion from continuous crop from a given soil (adjusted to 1.25 inches rainfall) in inches per year

R = cover factor (fallow or continuous row crop equals 100)

S = land slope in per cent (with 10% as standard)

L = length of the land slope in feet (with 72.6 feet as standard)

P = is the maximum 30-minute rainfall amount, 2-year frequency, in inches (with 1.25 inches as standard)

Equation (2-7) was later modified by Farnham, Beer, and Heinemann (1966) as follows:

$$E = 0.59\left[\frac{KR}{150}\right]P \left[\frac{R}{100}\right]\left[\frac{S}{10}\right]^{1.35} \left[\frac{L}{72.6}\right]^{0.35} \qquad (2\text{-}8)$$

where K, R, P are as defined in the universal soil loss equation, and the rest of the terms are as defined in Equation (2-7).

Gottschalk and Brune (1950) developed a method commonly known as TP-97. In this method, the average slope length is determined for the area in row crops and small grains. The predominant crop rotation is also determined. Tabulated values for soil losses from straight-row cultivation, contoured but not terraced, and contoured and terraced cropland are used to determine sheet erosion from cultivated croplands. These values are then adjusted for both the proportion of the watershed in clean-tilled row crops and predominant rotation. Sheet erosion from other sources are estimated at 350 tons per square mile per year.

Beer, Farnham and Heinemann (1966) compared the universal soil loss, Musgrove modified, and the TP-97 methods of sheet erosion prediction. The results showed that both the universal and the Musgrave modified soil loss equations gave comparable results. The TP-97 method gave twice as much computed soil loss as the other two methods. Of all the three methods, the modified Musgrave equation gave the lowest coefficient of variation and the highest coefficient of regression.

It is to be noted that in all the sheet erosion prediction equations mentioned above, an explicit term representing overland flow is missing. Since the effect of runoff on sheet erosion is known to be very important, the prediction of sheet erosion with any of the above equations may lead to gross error when applied to specific time periods.

The specific role played by runoff in the sheet erosion process was studied by Ellison (1945). He found that soil loss caused by overland flow alone was related to the square of the velocities. The loss was initially very high but decreases rapidly with time. When rainfall was applied simultaneously with overland flow, a significant amount of soil loss increase was observed. Aggregate analysis showed that the material in the runoff was much finer than the material in the splash. This indicates that the coarser soil particles originally in the splash could not be transported by the runoff and were deposited within the experimental plot.

The combined effects of raindrop energy and soil moisture on sheet erosion were investigated by Dragoun (1962). He used data from two small watersheds and found that the quantity of soil loss best correlated as follows:

$$Ls = E\ I_{30}\ (1 + Pa - Qa) \tag{2-9}$$

where

Ls = the quantity of sediment transported in a particular storm

Pa = antecedent precipitation for a five day period

Qa = antecedent runoff for a five day period in inches

E = total storm energy computed from Equation (2-4)

I_{30} = the maximum 30-minute intensity during the storm in inches per hour

Podmore and Merva (1969) conducted a study to obtain information on the transport of thin materials by thin film flow. They introduced the critical distance of transport of particles by thin film flow concept and several models based on Stokes law settling through a laminar boundary layer were derived. Critical distance was defined as the distance from the point of insertion of sediment in the flowing film to the point at which a maximum amount of material is deposited for predetermined particle size range. The results showed that the critical distance is generally independent of the particle size; decreases with increasing surface roughness; and generally increases with increasing slope for smooth surfaces while for very rough surfaces the opposite effect is found. They also found that Stokes law is not a satisfactory model of sediment transport mechanism.

Meyer and Monke (1965) studied the effects of slope steepness, slope length, particle diameter, and rainfall intensity on soil erosion by rainfall and overland flow using spherical glass beads. Their study showed that runoff erosion increased rapidly with increasing slope and length except at small slopes and lengths where essentially no erosion occurred. Rainfall plus runoff, as compared with runoff alone, increased the erosion of the small particles but decreased the erosion of the larger ones.

Runoff with rainfall caused greater erosion for the smaller particles but less erosion for larger particles as compared to the same runoff without rainfall. Increased sediment availability and runoff carrying capacity, due to raindrop-induced turbulence and splash, were more dominant for the more easily transported soil particles whereas decreased carrying capacity of the runoff due to decreased flow velocity from splash leveling of the soil bed and to raindrop-impact dissipation were dominant for the larger sizes.

A multiple regression analysis of the experimental data they obtained from trials where the slope steepness was 7 per cent or greater gave the equation of best fit as:

$$E_r = C\ (S - S_c)^{m'} (L - L_c)^{n'} D^{-0.5} \qquad (2\text{-}10)$$

where

E_r = soil erosion by runoff per unit width

C = constant

L = slope length

L_c = critical slope length or the slope length where E_r becomes zero for a given S and D

S = slope steepness

S_c = critical slope steepness or the slope steepness in which E_r is zero for a given L and D

m' = constant exponent whose value range from 2.0 to 2.5

n' = constant exponent approximately equal to 1.5

D = sphere diameter

In a recent laboratory study, Foster and Martin (1969) investigated the effects of unit weight or bulk density of soil and slope on soil erosion. Their study showed that slope has an effect on the amounts of soil erosion and runoff. The effect of unit weight on the amount of soil erosion was significant only during the early time period. The effect of the slope-unit weight interaction was, however, significant at all time periods. The effect of unit weight on the volume of runoff wassignificant at all time periods. The effect of the unit weight-slope interaction on the volume of runoff water was also significant.

The findings of Foster and Martin (1969) on the relationship between the quantity of erosion and slope is not in complete agreement with those of Meyer and Monke (1965) who concluded that an increase in slope (without qualification as to the slope limits) results in an increase in soil loss. Foster and Martin (1969) showed that erosion occurring on a slope increased to a maximum and then decreased with further increases in slope. They concluded that for a given unit weight, there is a unique slope from which the maximum amount of erosion will occur, and vice versa.

Several studies have been made attempting to formulate mathematical equations expressing the capacity of flowing water to transport soil particles. Citing previous studies, Meyer and Monke (1965) stated that the tractive force of runoff increases as the runoff velocity squared; the quantity of sediment it can transport as the velocity to the fourth power; and the size of the particle it can move increases as the velocity to the fifth power. But as yet there is no generally accepted analytical theory or satisfactory experimental results defining the sediment transport capacity of overland flow. Excellent discussions on particle transport by fluid flow over a flat surface of loose grains are given by Raudkivi (1967) and Vanoni and his associates (1960).

Erosion Models

Soil erosion modeling is a relatively new method for the investigation of soil losses. This may be explained in part by the lack of satisfactory analytical expressions useful for evaluating some aspects of the erosion process. Also because of the complex nature of the erosion process, manual solutions needed for the projections and correlation of data are generally cumbersome and limited in scope. With the advent of the digital computers, the traditional limitation of calculating speed is removed and simulation methods that are greatly expanded in scope are now possible. Satisfactory digital models simulating many phases of the hydrologic processes related to the soil erosion process are now available.

Existing erosion equations have been used to calculate the effects of slope shape on soil loss. Working with plots of slope lengths of 75 feet, Onstad _et al_. (1966) developed a model based on the universal soil loss and continuity equations and routed it through slope intervals of 5 feet. Results obtained for different slope shapes under simulated rainfall conditions indicated that on the average there was no difference between predictions using the model and predictions made by simple calculations using the universal soil loss equation. This is to be expected since the model was based on the universal soil loss equation and thus its accuracy is largely dependent on the latter. The results agreed with measured soil losses for wet and dry antecedent soil moisture conditions. Close inspection of their data, however, showed wide variations in accuracy for individual events.

Following the suggestion of Ellison (1947), Meyer and Wischmeier (1969) proposed a mathematical model to describe the process of soil erosion by water. Four subprocesses were considered and the relationships used in their models are as follows:

1. Detachment by rainfall, D_r

$$D_r = f(E, I, C, G, A, S')$$

$$D_r \propto E\ I$$

$$E \propto I^{1.14}$$

$$D_r = S_{dr}\ A\ I^2$$

where

E = rainfall kinetic energy

S' - soil factor

C = watershed cover

I = rainfall intensity (maximum 30-minute intensity)

G = watershed geometry

A = area of increment

S_{dr}= a parameter that varies with S, C, and G

2. Detachment by runoff, D_f

$D_f \propto$ Tractive force, T

$T \propto kV^2$

$D_f \propto V^2$

$V^2 \propto S^{2/3}\ Q^{2/3}$

$$D_f = S_f\ A\ (S_u^{\ 2/3}\ Q_u^{\ 2/3} + S_l^{\ 2/3}\ Q_l^{\ 2/3})/2$$

where

V = velocity of overland flow

Q = overland flow

k = constant

S = soil slope

S_f = soil factor

u,l = subscripts indicating upper and lower portions of the increment, respectively

3. Transport by rainfall, T_r

$T_r = f(S, I, S_p, G, U, C)$

$T_r = S_t\ S\ I$

where

U = wind factor

S_p = soil parameter

S_t = a parameter that varies with U, C, S_p, and G

4. Transport by runoff, T_f

$$T_f \propto k\ V^5$$

$$V \propto S^{1/3}\ Q^{1/3}$$

$$T_f = S_f\ S^{5/3}\ Q^{5/3}$$

where

S_f = soil factor and the rest of the terms are as defined above.

The above relationships were derived from empirical formulas and from some well known relationships in fluid mechanics. The study of Meyer and Wischmeier (1969) demonstrates two important concepts very relevant to erosion modeling:

1. Different processes are modeled separately allowing where possible, physical concepts to be used. The separate effects of these processes may be observed and varied independently.

2. The processes are separated into detachment and transport functions. These are then compared to determine whether it is sediment supply or sediment transport that is limiting, thus, predicting either erosion or deposition at a point on the profile.

Figure 1 shows the flow chart of the model simulating the process of soil erosion by water. The four erosion subprocesses are evaluated for each successive slope-length increment, and the soil movement is routed downslope as illustrated.

Following the development of the Stanford Watershed Model IV by Crawford and Linsley (1966), Negev (1967)

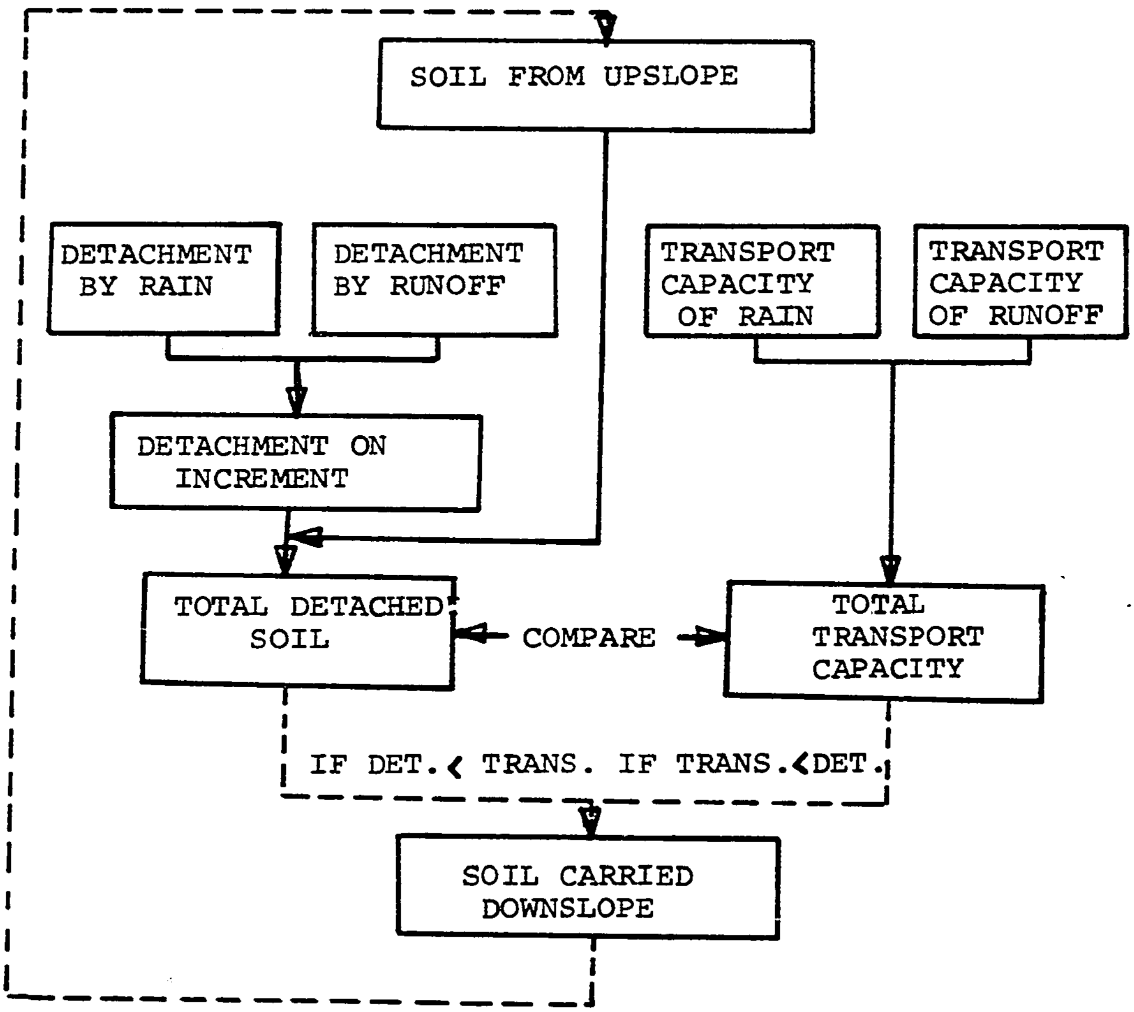


Figure 1. Flowchart of the model simulating the process of soil erosion by water. Four subprocesses, detachment by rain, detachment by runoff, transport by rain and transport by runoff are evaluated for each successive slope-length increment, and the soil movement is routed downslope as illustrated (Meyer and Wischmeier, 1969)

developed a sediment model on a digital computer. He superimposed his sediment model on the flow components of the watershed model. The sediment model distinguishes between the stream and the land surface. The stream surface is that part of the river channel system which includes rills and gullies while the land surface is the entire watershed excluding the stream surface. Figure 2 depicts the erosion and sedimentation processes as conceived by the model. Some of the relationships and concepts utilized by the model are explained below.

Land surface

As the raindrops hit the ground, soil particles of various sizes are splashed into the air. If overland flow is not taking place at that particular instant, all of the splashed particles will be deposited. If overland flow does occur, only the relatively coarser particles are deposited while the fine soil particles remain in suspension and are transported by the overland flow towards the nearest channel. The hourly quantity of fine soil particles produced by the splashed process (either transported by overland flow or redeposited) is computed in the model from the relation

$$RER = KRER\ HPP(t)^{JRER}$$

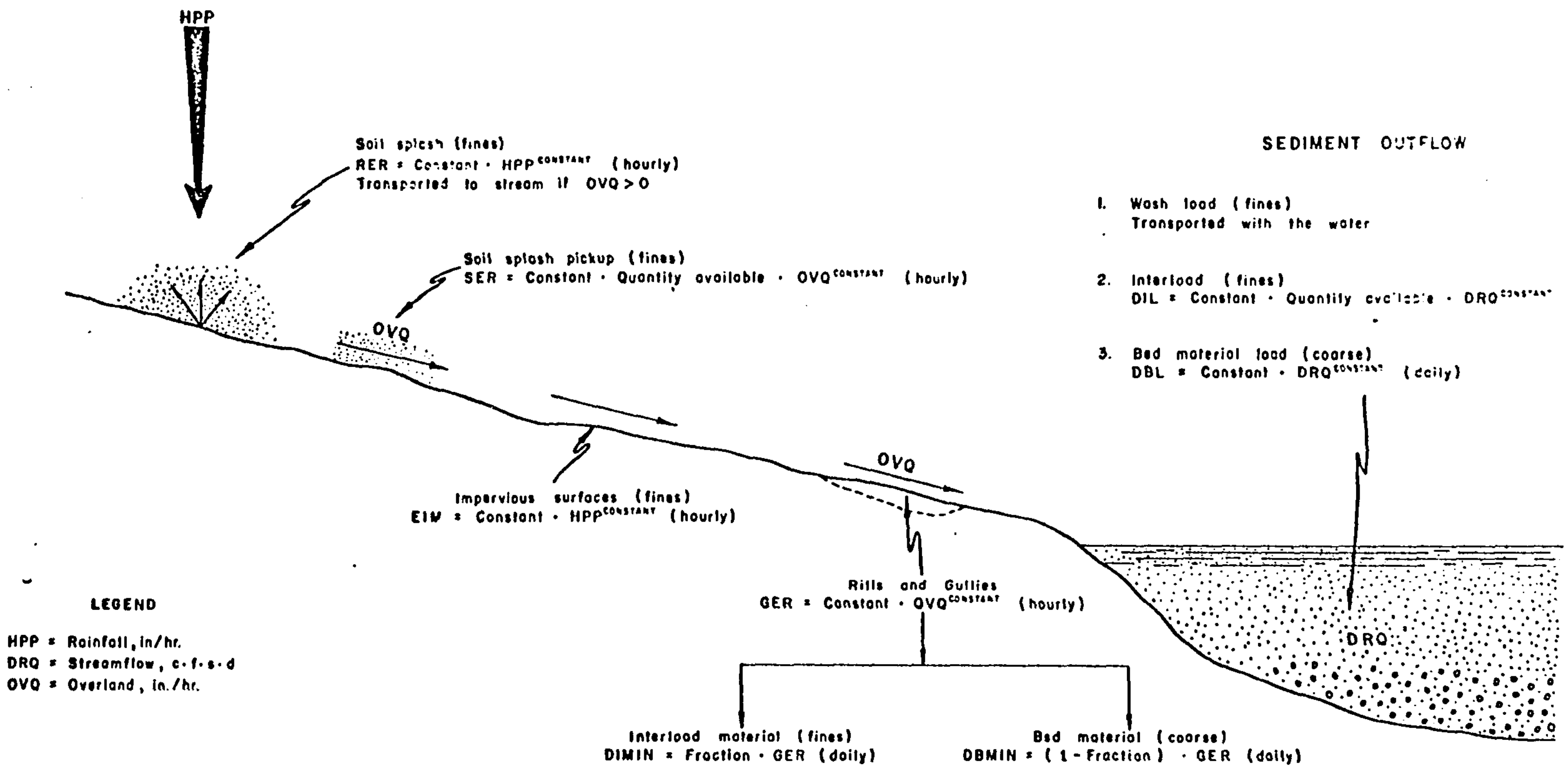


Figure 2. The erosion and sediment transport processes as conceived by Negev (1967)

where

RER = hourly quantity of soil splash, tons

HPP(t) = hourly rainfall during hour t, inches

KRER = a parameter that varies with soil type and cover

JRER = an exponent

The fine soil particles that had been detached by the raindrops but were deposited are left loosely on the ground. Upon the occurrence of the overland flow they may be picked up and added to the splashed soil that is already being transported. The hourly quantity of fine soil scoured in this process is computed by the relation

$$SER = KSER\ SRER(t-1)\ OVQ(t)^{JSER}$$

where

SER = hourly quantity of splash soil pickup, tons

OVQ(t) = hourly overland flow during hour t, inches

KSER = a parameter that varies with soil type and surface roughness

SRER(t-1) = the accumulated deposits of fine soil particles at the end of hour t-1, tons

$$= SRER(0) + \sum_{t=0}^{t=t-1} (RER_{OVQ(t)=0} - SER)$$

SRER(0) = the quantity of loose fine particles available in the land surface prior to the rainy season, tons

JSER = an exponent

The hourly quantity of soil particles picked up from impervious surfaces such as roads, roofs, and rock outcrops is estimated as

$$EIM = KIMP\ RER$$

where

EIM = hourly quantity of sediment contributed from impervious surfaces, tons

KIMP = a constant representing the ratio of the effective areas contributing to this process to the total watershed area

The total quantity of fine soil particles that is transported into the stream by surface runoff during any hour is

$$WLA(t) = RER + SER + EIM$$

The wash load WLA(t) is hydraulically routed through the stream system using the Time-area method.

Stream surface

Overland flow is generally characterized by shallow depth and low velocities. Under such conditions the erosive power of the overland flow is small. Where conditions of excessive runoff, steeper slopes, and sparse vegetal cover exist, the overland flow may cause significant amount of soil erosion. Since in a natural watershed neither the flow depth nor the soil type and cover are uniform, this erosion may tend to be more pronounced along certain paths of flow than others, resulting in the formation of rills. Rills may then enlarge to form gullies. The quantity of soil transported into the stream in this process is computed from the relation

$$GER = KGER\ OVQ(t)^{JGER}$$

where

GER = hourly quantity of sediment contributed from rills and gullies, tons

JGER = an exponent

KGER = a parameter that varies with the characteristics of the land surface.

The various parameters are obtained by trial and error procedure using recorded hydrological data and, hence, the applicability of the model is limited to basins having accurate climatological data. Of particular importance is the rainfall intensity because of the important role it plays in the production of sediment. It is also an important input in the simulation of overland flow by the Stanford Watershed Model.

Rowlison and Martin (1971) proposed a rational model describing slope erosion. This model is very similar to that proposed earlier by Meyer and Wischmeier (1969). Both models consider the detachment and transport functions of both rainfall and runoff. Rowlison and Martin, however, qualitatively evaluated the effects of slope and depth of water flow over the soil surface on the various erosion subprocesses in a laboratory experiment.

In the model they assumed that the detachment of soil due to runoff is negligible since the shearing stresses exerted by the flowing water are usually very small compared to the cohesive forces of most soils. A qualitative description of the soil detachment due to the rainfall impact is shown in Figure 3. Curve AB shows the general relationship between the detachment rate and the depth of the overland flow. The relationship between the detachment rate and slope is illustrated by curve AD which is for a given impact force. The interrelationship among the slope, detachment rate, and depth of overland flow is defined by the detachment rate surface ABCD.

Figure 4 shows the transportation rate surface as a function of slope and the depth of the overland flow. At zero depth of flow, the transportation rate which is due to rainfall alone is illustrated by curve EH. At zero slope there will be no overland flow and the net rainfall transportation will be zero as shown by line EF. The relationships between transportation rate versus depth of overland flow and transportation rate versus slope are assumed to be both exponential in nature as shown by curves HG and FG, respectively.

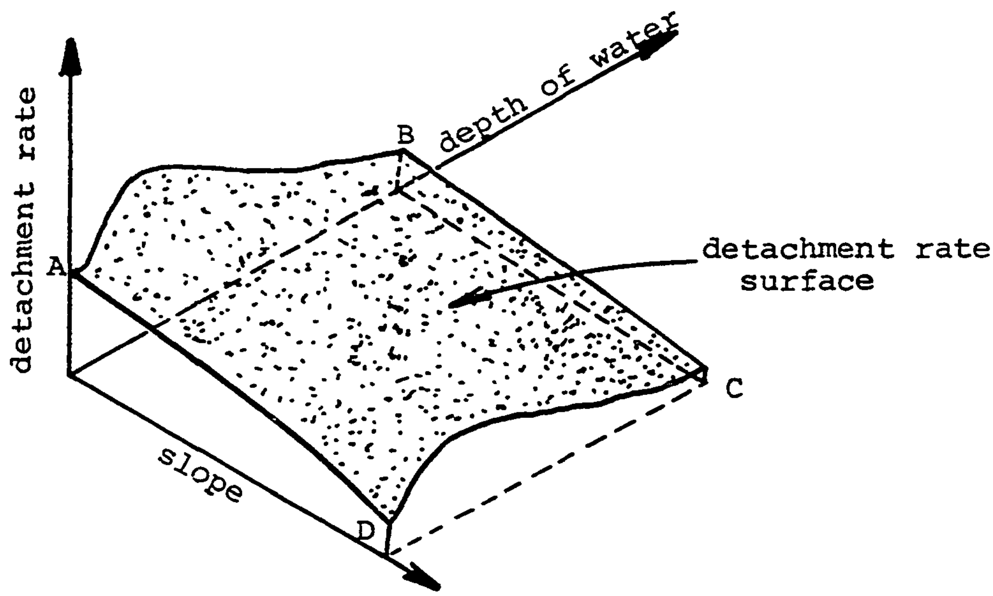


Figure 3. Potential detachment rate surface (Rowlison and Martin, 1971)

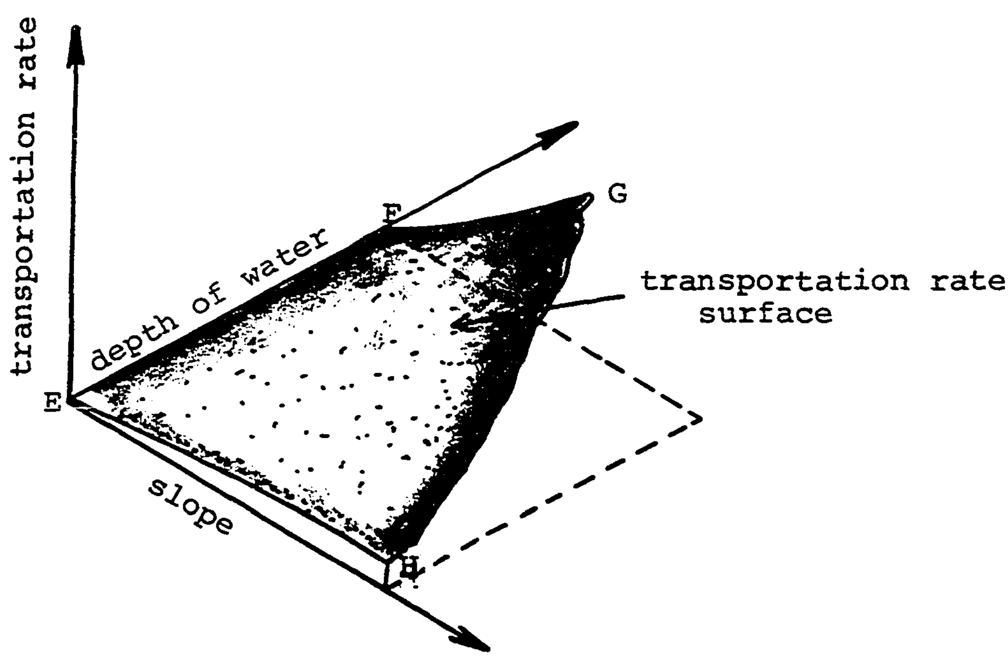


Figure 4. Potential transportation rate surface (Rowlison and Martin, 1971)

The rate that solid particles will erode from the soil surface will be controlled by the smaller of detaching capacity or transporting capacity. Stated another way, no more soil can be eroded than can be transported downslope. Using the limiting conditions, the surfaces of Figures 3 and 4 can be combined into one surface that defines the maximum erosion rate as a function of slope and the depth of the overland flow as shown in Figure 5.

As a summary, it should be mentioned that the models proposed by Rowlison and Martin (1971) and Meyer and Wischmeier (1969) were not published for sediment prediction but as research developments. They may be considered as qualitative hypotheses designed to serve as frameworks for quantitative models of soil erosion by water.

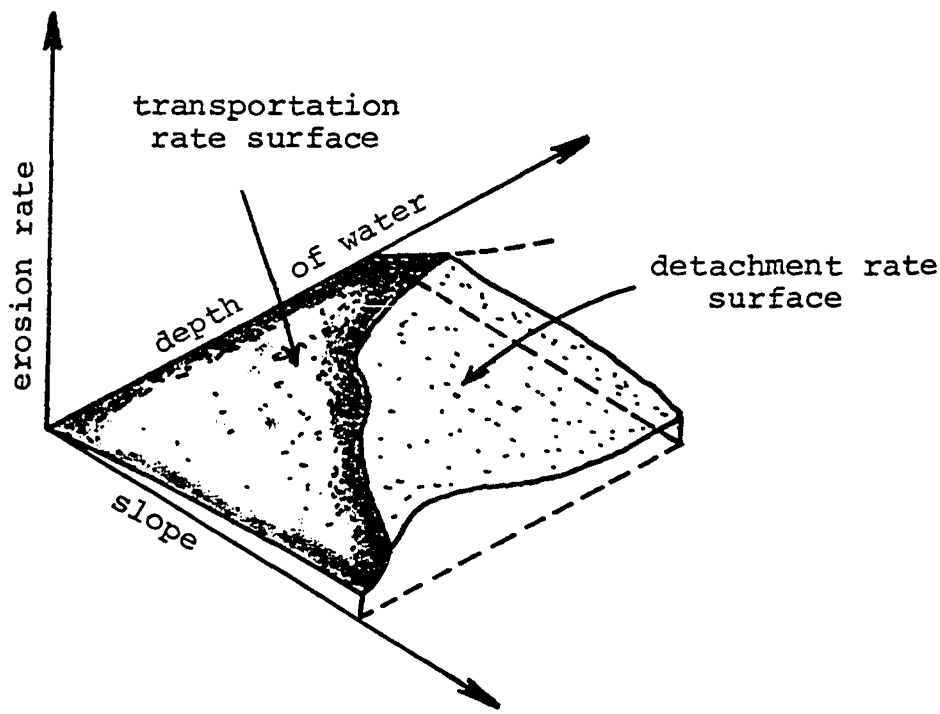


Figure 5. Surface of maximum erosion rate (Rowlison and Martin, 1971)

CHAPTER III. WATERSHED MODELING

Introduction

During the past 15 years, a very significant amount of effort has been directed toward hydrologic modeling. Some model builders have used an arrangement of analog components. Others have used a reduced scale laboratory replica of the natural system.

With the advent of high speed digital computers, comprehensive mathematical models in digital computer programs were made feasible. Such models are usually broad and complex and are usually dependent on previous works. Many workers have contributed ideas and methods that are influential in their developments. Background information on the developments of these models are given by Crawford and Linsley(1966), Haan (1967), DeBoer (1969), and Larson (1971).

Mathematical hydrologic models are of two general types - deterministic and stochastic. Stochastic models use the statistical properties of existing records and probability laws to generate future events. Very often, small agricultural watersheds have very limited hydrologic data. Those that have sufficient years of record are usually undergoing significant modifications. Their past records, therefore, cannot be used directly as bases for future predictions. For this reason, this study is concerned primarily with deterministic watershed models.

A deterministic watershed model represents the many hydrologic processes that occur in a watershed by a series of mathematical relationships. It consists of many component models, each representing a certain hydrologic process such as infiltration or evapotranspiration. For each unit of time, the individual components are used in combination to simulate moisture movement within, into, and out of the watershed.

The functional relationships describing a hydrologic process are of two general types which Larson (1971) referred to as physical and conceptual. Physical functions are based on a working knowledge of the actual process and are generally based on measurable parameters. Conceptual functions, on the other hand, are based on a knowledge of the processes which are related either physically or empirically to the actual process being represented. This often requires the use of watershed parameters which cannot be measured directly and, therefore, must be evaluated by fitting or trial and error.

One of the earliest and most widely used deterministic watershed model is the Stanford Watershed Model (SWM) developed by Crawford and Linsley (1966). It is a comprehensive and also a generalized model since it can be applied to different watersheds by changing the input parameters. As do all large and comprehensive watershed models, it has become almost a living entity as it is continuously developed to meet new needs. It is because of this high degree of flexibility that a modified Stanford Watershed Model which is commonly referred to as the Kentucky Watershed Model (KWM) is used in this study.

The Kentucky Watershed Model

Crawford and Linsley (1962) published the original version of the Stanford Watershed Model (Mark II). The most widely publicized version (SWM IV) appeared in 1966 (Crawford and Linsley, 1966). The same Stanford group more recently developed a system called Hydrologic Simulation Programming incorporating a much more sophisticated routing technique capable of simulating simultaneous flows at a large number of points within the watershed.

The original version of the SWM was written in Burroughs computer language (BALGOL) used by the Stanford University Computer Center. In spite of its great potential, a number of factors have deterred its widespread use. Those frequently mentioned (Liou, 1970) are: programming in a little used computer language; difficulty in understanding the model as complicated by its bulk; unfamiliarity of many hydrologists with the digital modeling process; and the difficulty new users experience in acquiring the skill needed in estimating the numerous parameters required as input data.

Realizing these limitations, James (1970) and his associates at the University of Kentucky translated the

Stanford Watershed Model III as reported by Anderson and Crawford (1964) into Fortran IV, which because of the much more widespread use of the computer language, contributed toward increasing the model's use. Later, a number of improvements presented in the SWM IV were added along with other adaptations. They also made pioneering effort in developing a self-calibrating streamlined version of the model (OPSET) in order to eliminate the trial and error approach to parameter estimation. They called their SWM version the Kentucky Watershed Model (KWM) more to absolve the Stanford group of the blame for the differences rather than to deny them credit for original program development. Their work was reported in three parts. Liou (1970) reported the development of the self-calibrating version (OPSET) and provided program listings for both the OPSET and KWM. Ross (1970) gave detailed instructions on the use of both the KWM and OPSET. James (1970) evaluated the relationships between streamflow patterns and watershed characteristics through the use of OPSET.

The major elements of the SWM or KWM are shown on Figure 6. Precipitation and potential evapotranspiration are the main input data. Additional climatological data such as temperature, solar radiation, potential snow evaporation are used where snowfall is significant. The snowmelt simulation is modeled by the snowmelt subroutine whose major elements are shown on Figure 7.

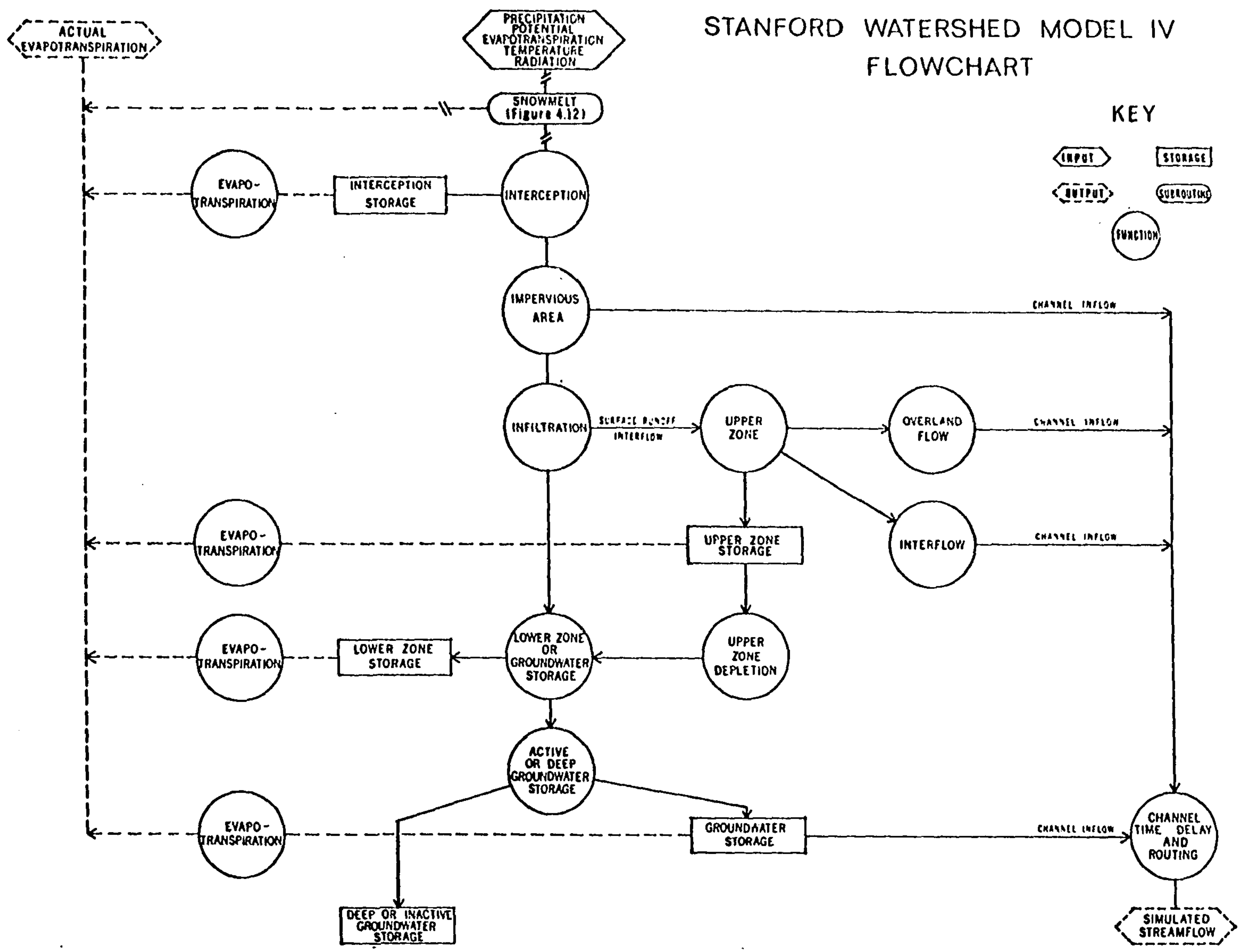


Figure 6. Flowchart of the Stanford Watershed Model IV (Crawford and Linsley, 1966)

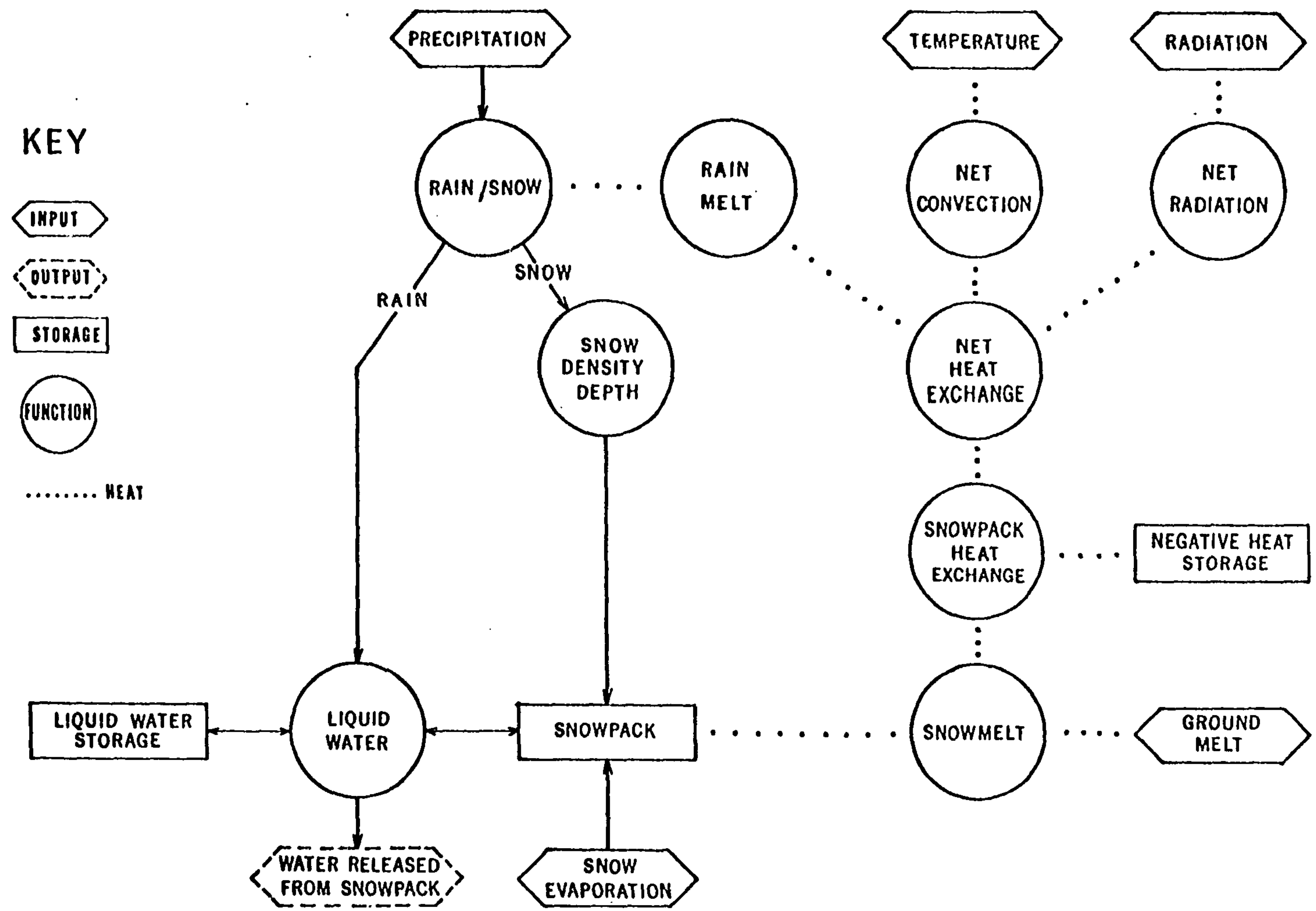


Figure 7. Stanford Watershed Model snowmelt subroutine flowchart (Anderson and Crawford, 1964)

The calculations begin from known or assumed initial moisture storage conditions and yield continuous simulation of the hydrologic cycle. Precipitation form is differentiated as to rain or snow. Depending on its form, precipitation may be stored in the snowpack and/or in the three major soil moisture storage categories shown on Figure 6. The model keeps an account of all incoming water until it leaves the watershed via evapotranspiration, streamflow, or subsurface flow.

The soil moisture and groundwater profiles are represented by the upper, lower, and the groundwater storage zones. The upper and lower storage zones regulate infiltration, overland flow, interflow, and inflow into the groundwater storage. The upper zone includes both interception and depression storages. Interception is governed by watershed cover and the current volume of interception in storage. The initial precipitation enters interception storage until a preassigned volume is filled. It continues during a storm as a result of evaporation losses which are assumed to occur at a corresponding potential evapotranspiration rate. Depression storage is governed by the watershed surface configurations. It is represented together with interception by a nominal upper zone storage level (UZC) and a watershed parameter which serves as an index of the degree to which UZC changes with time as a result of cultivation practices and other factors.

The complex process of infiltration is modeled by a cumulative frequency distribution of infiltration capacity which represents a variable infiltration function over a watershed. As shown on Figure 8, this distribution is assumed to be linear from zero to a maximum value. It is also assumed that interflow is directly proportional to the infiltration capacity. Thus, the tendency for infiltrating water to become interflow is assumed to be directly proportional to the infiltration capacity.

The simulated reaction of a watershed to a given moisture supply, PEP, is shown on Figure 8. The incoming moisture is first subject to the operation of the cumulative infiltration capacity functions which govern interflow detention storage and the direct flow into the long term lower zone and ground water storages. The amount of moisture in surface detention which is subject to the operation of the upper zone storage is calculated.

The interflow distributions and the infiltration capacity at any given point and time are functions of the current lower zone storage and four watershed parameters. These parameters pertain to a nominal lower zone storage level (LZC), a basic maximum infiltration rate (BMIR), and interflow relative to overland flow factor (BIVF), and an index to the seasonal variation in the basic maximum infiltration rate

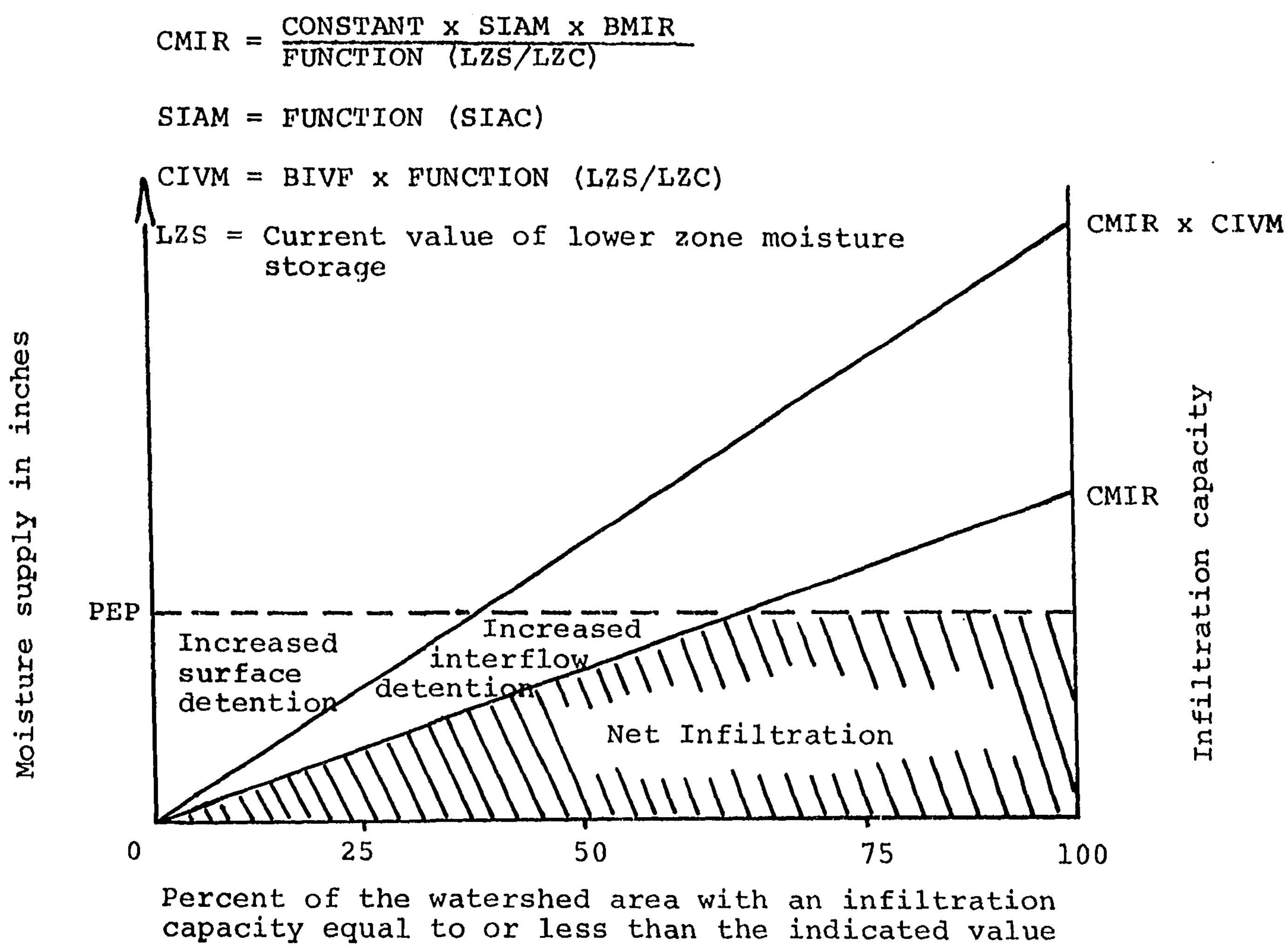


Figure 8. Model for estimating infiltration capacity (Crawford and Linsley, 1966)

(SIAC). The above parameters are denoted by the symbols assigned to them in the program listing given on Appendix A in order to facilitate the understanding of the computer programs.

The quantity of net infiltration into the lower zone at any given time is determined by the current value of CMIR. Similarly, the current value of the product CMIR x CIVM determines the time distribution of runoff by controlling the ratio of increments to surface detention leading to overland flow and interflow detention. As shown on Figure 8, the value of CMIR at any given time is a function of the basic maximum infiltration rate and the seasonal infiltration adjustment constant and the current value of the dimensionless ratio LZS/LZC. The same dimensionless ratio together with the parameter BIVF determine the current value of the variable CIVM. The various nonlinear relationships used to estimate CMIR and CIVM are based on empirical observations and are explained in details by Crawford and Linsley (1966). The value of CMIR decreases rapidly with the ratio LZS/LZC while that of CIVM increases gradually with the same ratio.

The water that remains in surface detention after direct infiltration is removed from the upper zone by evaporation, surface runoff, and delayed infiltration into the lower zone and groundwater storage. Evapotranspiration occurs from the upper zone storage at a potential rate.

The overland flow is modeled by means of a continuity equation relating the rate of discharge for overland flows to the volume of surface detention. The basic relationship for overland flow discharge rates is given in terms of the moisture supply rate, average amount of surface detention for a time interval, the amount of surface detention at equilibrium for a given supply rate, and the slope length and the surface roughness coefficient of the flow plane.

In the model, the groundwater supply rate is simulated directly at the mouth of the watershed. The sum of overland flow and interflow is simulated as channel inflow. The channel inflow is routed downstream to the gage point using a simple empirical routing technique. In this method a channel time-delay histogram is derived by planimetering contributing areas, estimating the channel flows at successive points in the stream channel system, and calculating the time of flow to the watershed outlet. The histogram is used to translate the channel water through a hypothetical reservoir.

Operation of the Kentucky Watershed Model

A program listing of the Kentucky Watershed Model together with the superimposed erosion model is given in Appendix A. By using the appropriate control options that are listed in Appendix B, the erosion model may be excluded from the analysis. The watershed model portion is similar to that given by Liou (1970) except for some modification and adaptations to Iowa conditions.

Ross (1970) discusses the details of the operation of the KWM and lists typical input data. His report is intended to be a manual for understanding the many facets of programs use. Unfortunately, however, the KWM programs use a complicated subroutine to read input data. This subroutine is written in machine language to read input data punched in a free format, or format varying from one user to the next. The details of this subroutine are not covered in their reports and, hence, the program cannot be readily used. Furthermore, problems are usually encountered in trying to adapt this subroutine from one computer operation system to another.

Due to the above considerations, all the read statements were rewritten in convenient formats as shown in Appendix A. As a result of this and other program modifications, the operation of the model listed in Appendix A is somewhat different from that outlined by Ross (1970). Also, Ross did not use the snowmelt subroutine and, hence, it is not included in his discussions. Anderson and Crawford (1964), however, outlined the operation of the subroutine. To make full use of the above mentioned works, the following discussions attempt to be consistent with those of Ross and Anderson and Crawford wherever possible.

Input data

The required input data for the program listed in Appendix A are of six general types:

1. Control options that specify the type of input and output for a particular run.

2. Watershed parameters. These include the time-delay histogram as well as the general physical parameters, land surface parameters, and channel system parameters required by both the KWM and the superimposed erosion model.

3. Input data indicating the dates during the water year in which some parameters are in effect. These also include the dates when pan evaporation measurements are discontinued in late fall and started again in early spring. Such dates usually vary from one water year to another.

4. Input data describing climatological events.

5. Input data describing initial moisture conditions prevailing at the start of the first year to be synthesized.

6. Input data indicating the daily amounts of streamflow, diversion, and suspended sediment loads.

The input data relating to the erosion model will be discussed more in details in the following chapters. Those that pertain to the KWM are briefly discussed below.

Control options Twenty control options are available in the model. Of these, only the first sixteen are working options as the last four are reserved for future program expansion. Each of the sixteen options are explained in Appendix B. Options 1, 4, 5, 6, and 14 provide the user with the opportunity to request additional output.

Option 2 allows the user to divide the hourly rainfall among 15-minute periods following a typical storm distribution rather than divide it equally. This option calls a subroutine PREPRD into action and divides hourly precipitation into a distribution described by Liou (1970). It is normally used only for small watersheds having times of concentration of less than one hour where the 15-minute distributions of rainfall can have a very significant effect on the flood peaks.

Options 3, 8, 9, 11, and 16 provide flexibility in using various types of input data depending on available records. Option 9 is normally used if streamflow records are available. Where such records are lacking, options 4, 14, 15, and 16 cannot be exercised. Option 15 specifies if the erosion model is to be included in the analysis. Obviously, option 16 cannot be used if option 15 is not in effect.

Option 7 calls into action the snowmelt subroutine. This option is used where snowmelt is significant. To use this option, additional input data such as those shown in Figure 7 are needed.

Option 10 is used when two different watersheds are synthesized in the same computer run. Option 12 offers the user the choice of a fifteen or sixty minute channel routing time increment. The time-delay histogram must correspond accordingly to the option taken. Option 13 provides a means for making the time routing of storm hydrographs nonlinear by causing the flow to move downstream faster during periods of higher flows.

Watershed parameters The watershed parameters required by the KWM may be divided into two general types: 1) measurable parameters or those parameters that can be reasonably estimated from observed watershed characteristics and 2) parameters that have to be fitted or estimated through the comparison of observed and predicted statistics.

The measurable parameters are:

1. BDDFSM is the basic degree hour factor (in/hr).
2. ELDIF is the elevation difference (thousand feet) from the base temperature gage location to the mean elevation of the watershed.
3. XDNFS is the index to the density of new fallen snow.
4. AREA is the total area of the watershed (square miles).
5. FIMP is the fraction of the watershed being impervious.
6. FWTR is the fraction of the watershed covered with water surface.
7. FFOR is the fraction of the watershed being forest.
8. VINTMR is the maximum depth of precipitation interception (in).
9. FFSI is the fraction of the snow falling on the forest area that is intercepted. This is assumed to be lost directly to evaporation, without ever reaching the snow on the ground.

10. SPBFLW is the snowpack basic maximum fraction in liquid water. It is an index to the amount of water which will be held in the snowpack before water produced at the surface is able to drain toward the bottom of the snowpack. Very little data are available on the magnitude of this parameter and its variation with snow density. Studies by Anderson and Crawford (1964) show a range for SPBFLW from 4 to 6 per cent of the water equivalent of the snowpack.

11. SPTWCC is the snowpack minimum total water equivalent for maximum basin coverage (in). In the model it is assumed that when the water equivalent of the current snowpack is less than SPTWCC the ratio of actual melt to 100 per cent cover melt is directly proportional to the ratio of the current snowpack water equivalent to SPTWCC.

12. DSMGH is the rate of daily snowmelt from ground heat. The model assumes a constant DSMGH. In areas with shallow snowpacks and long cold periods DSMGH would be zero. Otherwise, Anderson and Crawford (1964) suggest a value of 0.01 or 0.02 inches.

13. PXCSA is the precipitation index for changing the snow albedo. In the model a snow albedo index (SAX) is set to vary from zero to fifteen, with zero signifying maximum albedo and 15 a well aged snow surface. The value of SAX is decreased by one whenever new snowfall accumulation reaches PXCSA and increased by one whenever snow accumulation is down to PXCSA/2 or each day to account for snow aging.

14. MRNSM is the maximum rate of negative snowmelt (in). This is an index to the cold content and the extent of liquid water content refreezing of the snowpack. It is used to estimate the amount of negative melt as based on some empirical relationships developed by Anderson and Crawford (1964).

15. SPM is the snow precipitation multiplier. It corrects for gage catch deficiencies that may exist when precipitation is in the form of snow. Such deficiencies may be as high as 60 per cent for winds of 35 miles per hour (Linsley, et al. 1958). Based upon prevailing wind conditions, this

parameter may be estimated. It can also be determined by comparing synthesized and observed snowmelt runoffs.

16. RMPF is not a parameter but an output option which is read together with some of the watershed parameters. It is the requested minimum daily peak flow to be printed. Instantaneous streamflow due to direct runoff must reach its value sometime during the day before the 24 hourly flows for that day are printed.

17. RGPMB is the ratio of the average rainfall over the basin to the average rainfall at the base gage.

18. GWETF is the groundwater evapotranspiration factor. This estimates the current rates at which swamp vegetation and deep rooted plants are drawing water from that below the water table. Its value is usually zero and where it is not it may be estimated by trial and error.

19. SUBWF is the amount of water entering or leaving the basin through subsurface flow not measured by the stream gages. For most basins this parameter is zero and where it is not it could be estimated by trial and error.

20. OFMN is the Manning's roughness coefficient for overland flow on the flow plane.

21. OFMNIS is the Manning's roughness coefficient for overland flow over impervious surfaces. Estimates of the above roughness coefficients are given by Crawford and Linsley (1966) and Chow (1959).

22. OFSS is the average slope in feet per foot of the overland flow surfaces perpendicular to the receiving channel. This may be estimated from spot measurements or by using a topographic map of the watershed.

23. OFSL is the overland flow slope length. It indicates the average distance that surface runoff must travel before reaching a channel.

24. CHCAP is a measure of the channel capacity. Its value is used to distinguish between flood flow and contained flow so that the channel storage

routing index may be changed accordingly. It may be estimated from a profile analysis of the channel system. It may also be estimated as the "base" used by the U.S. Geological Survey in determining which flood peaks to list in their Surface Water Records.

25. CTRI is an array of the channel time-delay histogram. The elements of the time-delay histogram may be found by estimating the time of concentration of the watershed, the horizontal length and the slope in feet per foot of the channel. The horizontal length is the measured distance from the most remote point to the outlet of the basin. The difference in elevation between these points divided by the length yields an estimate of the average slope. The time of concentration divided by the length gives the average velocity of flow of the water in the channel. When multiplied by the time routing increment this average velocity yields the stream distance for separating isochrones on a map of the watershed. The area bounded by each pair of isochrones is planimetered, and the fraction of the watershed contained between each pair is estimated. The time-area histogram is a tabulation of these fractions, proceeding in an upstream direction.

The second type of watershed parameters include the following:

1. BUZC is the upper zone nominal storage level (in). Its magnitude is quite small compared to the lower zone storage capacity.

2. LZC is the nominal storage level that represents the median value of lower zone moisture storage (inches). It is roughly equal to 1.2 times the water holding capacity of the lower zone.

3. BMTR is a measure of the basic maximum infiltration rate (BMIR). It is used in estimating the value of BMIR and, hence, CMIR. These first three parameters LZC, BUZC, and BMIR are interrelated. They may be estimated by trial and error or by examining the physical effects of storage and infiltration rate interactions as each parameter is physically defined.

4. SUZC is an index for the upper zone storage adjustment. Its purpose is to adjust BUZC in order to account for seasonal changes in its value as a result of the effects of vegetation and cultivation practices.

5. GFIE is an index of the effect of ground freezing on the infiltration capacity of the soil. It may be used to drastically reduce the infiltration capacity during the winter months when the soil surface is frozen.

6. SIAC is a seasonal infiltration adjustment constant. Its purpose is to modify BMIR to take into account the effect of vegetation and cultivation practices.

7. ETLF is an index used to estimate the maximum rate of evapotranspiration. The maximum rate is estimated as the product of ETLF and the ratio LZS/LZC. This maximum rate is used to estimate the current actual evapotranspiration in a manner shown on Figure 9. Crawford and Linsley (1966) recommend ETLF values ranging from 0.20 to 0.30 inches depending on the watershed cover.

8. BIVF is the basic interflow volume parameter. It is used to define the variable CIVM in Figure 8. It controls the shape of the hydrographs by regulating the amount of moisture entering interflow. Increasing BIVF will increase CIVM thus, reducing the storm peaks and extending the hydrographs' recession limbs.

9. BFRC is the base flow recession constant.

10. BFNLR is a base flow nonlinear recession index. It is used to provide a curvilinear base flow recession. Its value is normally between 0.90 and 1.0. When it is equal to 1.0, the model will use a linear base flow recession.

11. IFRC is the interflow recession constant. Its value as well as those of BFRC and BFNLR may be estimated by trial and error. They may also be found by graphical or mathematical analysis of hydrographs.

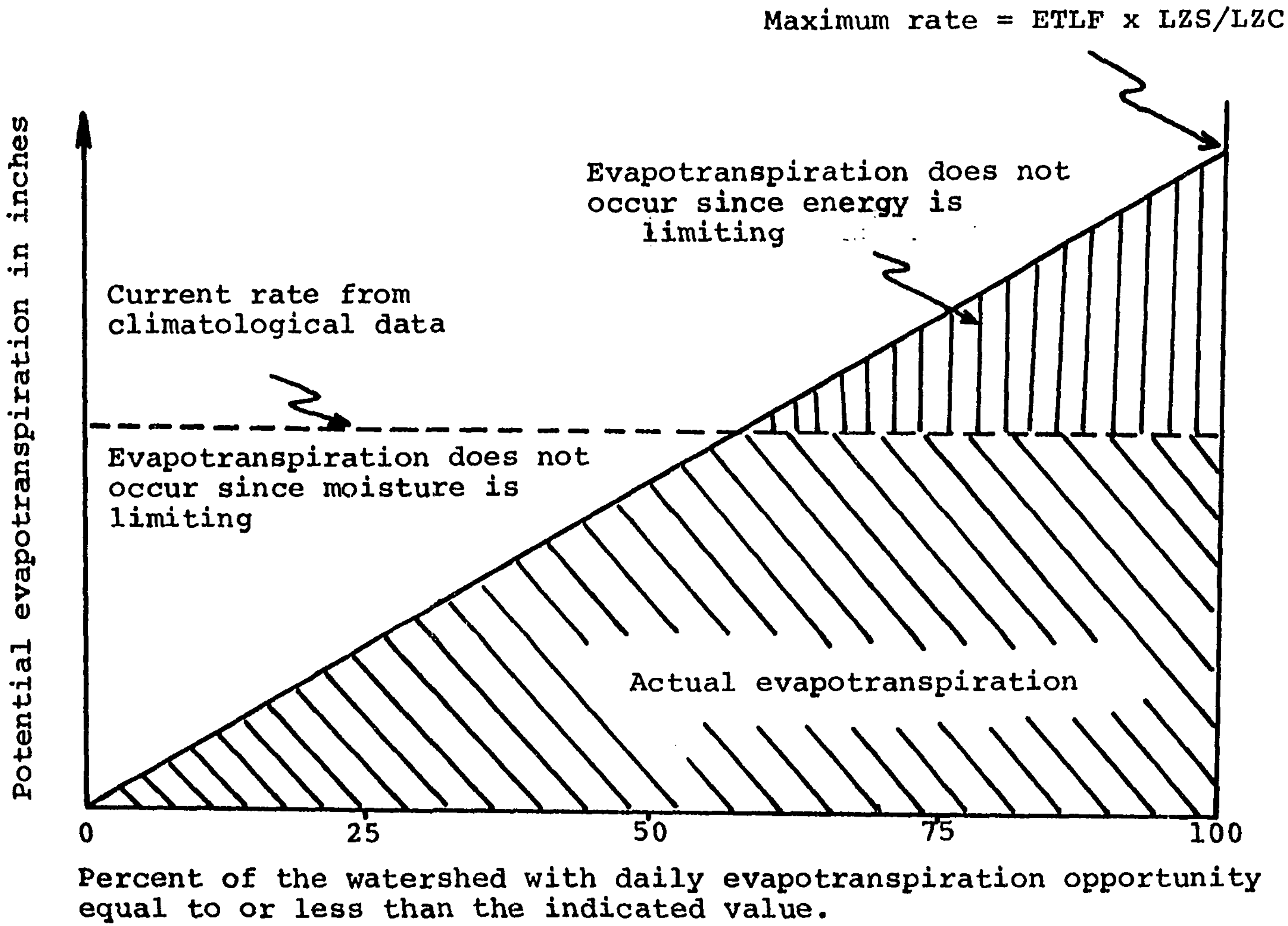


Figure 9. Cumulative frequency distribution of actual evapotranspiration over a watershed (Crawford and Linsley, 1966)

12. CSRX is a streamflow routing index used to account for channel storage when flows are less than one-half the channel capacity (CHCAP). To simulate channel attenuation or storage, the outflow hydrographs produced by channel translation (using the time-area histogram) are routed through a hypothetical storage system or reservoir. The routing equation used in the model is

$$O_2 = \bar{I} - CSRX(\bar{I} - O_1)$$

where O_2 is the reservoir outflow at the end of the selected time interval, O_1 is the outflow at the beginning of the interval and $\bar{I}$ is the average inflow during the time interval.

13. FSRX is a streamflow routing parameter used to account for channel as well as flood plain storage when streamflows are greater than twice the channel capacity. Under such flow condition FSRX is substituted for CSRX in the routing equation. When the flow is between one-half and twice CHCAP, the model interpolates between CSRX and FSRX. When the average inflow $\bar{I}$ in the routing equation is zero, the channel routing parameter becomes a recession constant for the water in channel storage. The values of CSRX and FSRX may then be estimated by analyzing the observed hydrographs.

14. EXQPV is an exponent which is used to vary the velocity with flow rate. It is used only when option 13 is in effect. The time routing of the storm hydrograph is made nonlinear by making the flow velocity proportional to the flow rate raised to the exponent EXQVP. Ross (1970) recommends a value of about 0.25 for EXQVP.

Input data indicating relevant dates

1. NDTUZ is the approximate date of the year in which the thawing of the upper soil surface begins. In Iowa this usually occurs during the first or second week of March. In the model it is assumed that from day one (January first) through NDTUZ the soil surface is frozen thus reducing infiltration drastically. During this period the basic maximum infiltration rate index, BMTR, is divided by the parameter GFIE in order to obtain the basic maximum infiltration rate, BMIR. Otherwise, BMIR is set equal to BMTR.

2. NDIM is the last day in which pan evaporation measurements are taken. After this date the measurements are stopped for the duration of the winter season. This day usually falls in the second or third week of November in Iowa.

3. NDFM is the day (going from 1 to 365 or 366) in which pan evaporation measurements are restarted after being temporarily stopped during the winter months. In Iowa this usually falls in the first week of April.

Climatological data   Hourly precipitation and daily potential evapotranspiration are the major climatological data required by the model. In addition to these, the snowmelt subroutine requires solar radiation, snow potential evaporation, snow albedo, and daily maximum and minimum temperature data.

Hourly rainfalls   Hourly rainfalls should be obtained from recording rain gages best representing the watershed. The Environmental Data Services, National Oceanic and Atmospheric Administration of the U.S. Department of Commerce compiles and publishes hourly precipitation records from recording rain gages scattered all over the United States. On rare occasions, records from locally maintained recording rain gages are also available.

In the event that two or more recording rain gages represent the storm patterns within the watershed, the average hourly rainfall may be estimated by using any of the areal rainfall averaging techniques such as the arithmetic mean, Thiessen, and isohyetal methods.

Daily rainfall from storage rain gages should also be obtained where they can be averaged with the recording rain gage totals. The model is set up to read and average data from one recording and one storage gage only. When more than one of each type of rain gage are to be used, the model must be modified or the averaging for each gage type must be done first before the final averaging of the recording and storage gages averages. Another alternative is to modify the model structure so as to provide the option of subdividing a watershed into segments and modeling runoff as the sum of the segment totals. Watershed segmentation is one aspect of the Stanford Watershed Model that does not exist in the Kentucky Watershed Model.

The averaging of the storage gage totals with the recording gage totals may be accomplished by determining the fraction of the total watershed area represented by the storage gages. This fraction serves as the storage gages weighting factor (WSG). The daily rainfall in the watershed is computed as the sum of WSG times the storage gage total plus (1 - WSG) times the recording gage total. The hourly rainfalls are then multiplied by the ratio of the daily rainfall average and recording gage daily total to obtain the average hourly rainfalls within the watershed.

Problems may arise in comparing the storage gage daily rainfalls with those of the recording gage daily totals as a result of the differences in times over which these daily measurements were obtained. To correct this, the model requires the storage gage reading time, SGRT. This is the integer value on the 24-hour clock corresponding to the hour closest to the reported reading time. In the event that a storage gage is relocated, an option is available for reading new SGRT and WSG values (SGRT2 and WSG2).

Potential evapotranspiration The model uses pan evaporation to estimate the actual evapotranspiration losses from the watershed. The model assumes that the evapotranspiration losses occur from the upper zone first, and in the event that all the upper zone moisture has evapotranspired, from soil moisture storage (LZS). Daily pan evaporation measurements are used at times when such measurements are available. During the rest of the water year when such measurements are discontinued, the pan evaporations are estimated by the model.

To estimate actual evapotranspiration losses, existing local data showing the ratios of actual evapotranspiration to pan evaporation at various times of the year are used. These ratios are not included in the input data but are incorporated in the model structure. If the model is to be used in places other than Iowa a slight modification of these ratios might be desirable.

An option is included in the model to read average pan evaporation values over fixed ten-day periods. These periods may be determined by reading the listing given in Appendix A. They are also specified by Ross (1970). This option is used only when the closest evaporation pan is too far away for daily fluctuations in evaporation to be representative of the conditions over the watershed. Another option in the KWM as listed by Liou (1970) is to use only an estimate of the potential annual lake evaporation. This option is used only when the first two options cannot be exercised. The KWM uses a subroutine to subdivide the annual lake evaporation average over the days of the year. This option and, hence, the subroutine is not included in the model listed in Appendix A in order to save computer compilation time. It is, however, discussed by Ross (1970) and listed by Liou (1970).

Solar radiation Hourly solar radiations incident on the watershed are used in the synthesis of streamflow due to snowmelt. Such data are difficult to obtain as only daily totals at very few stations are published by the Environmental Data Services, National Oceanic and Atmospheric Administration of the U.S. Weather Bureau. This is one of the reasons why the snowmelt subroutine of the SWM has not been widely used even in areas where there is significant snowfall.

The Stanford Watershed Model described by Anderson and Crawford (1964) uses daily net solar radiation from which hourly values were calculated by means of a relationship expressing hourly radiation as a percentage of the total. This relationship is missing in the KWM snowmelt subroutine.

The snowmelt subroutine listed in Appendix A is similar to that listed by Liou (1970) except for a few modifications. The subroutine assumes a fixed 10-hour day for the duration of the snowmelt season. It further assumes an equal distribution of the daily radiation total among the 10 hours of the day. The input data are, therefore, the hourly solar radiation values which in effect are the daily totals divided by ten. The model requires input data only for the months of November, December, and from January through April of each water year. For the rest of the water year when there is usually no snowfall, a fixed value is assumed. Such value has no effect on the operation of the model.

In the program listing on Appendix A, the day 366 corresponds to the 29th day of February of each leap year. When the current water year does not contain such a day, its value will not be used and, hence, any convenient value may be used. This is also true for the other snowmelt input data such as daily minimum and maximum temperatures.

The assumption of equal hourly distribution of solar radiation within a day is not valid where accurate reproduction of hourly snowmelt is needed. Given the scarcity of solar radiation data coupled with the hourly fluctuations in incident net radiation from one watershed to another as a result of atmospheric interference, this assumption offers a great deal of simplification without further loss of accuracy in daily or monthly snowmelt totals.

Snow albedo The model uses fifteen estimates for the fraction of the incoming solar radiation reflected by the snow surface depending on the value of the snow albedo index, SAX. A clean dry snow surface will probably reflect about 80 per cent of the incident short-wave radiation. As the snow ages, its albedo may drop to as low as 50 per cent. The 15 snow albedo estimates (FIRR) will normally be within this range.

Temperature Representative daily minimum and maximum air temperatures are required for the months in which incident hourly radiation values are also required. For the rest of the water year (May through October), it is assumed that no snowfall occurs or that if some snowfall does occur, it does not stay long on the ground.

The model assumes the daily minimum and maximum temperatures occur at 4 (4 a.m.) and 16 (4 p.m.) hours of the day, respectively. After correcting for lapse rates, the model calculates hourly values by fitting a sine curve to the two temperature extremes. The points of inflection of such a curve are at 10 and 22 hours of the day.

Snow evaporation The model reads average potential snow evaporation for fixed 10-day periods and, hence, only 37 input values are required. Snow evaporation values may be estimated with reasonable accuracy. They are close to zero even during periods of heavy snow accumulation and zero otherwise. Since they are relatively small, errors in their estimate will not significantly affect the water balance of a watershed.

Initial moisture conditions The streamflow synthesis begins on October first which is the first day of any water year. For the first water year to be run, estimates of the initial moisture storages in interflow (IFS), the upper zone (UZS), the lower zone (LZS), and groundwater (GWS) must be supplied. In addition, an initial estimate of the base flow nonlinear recession index (BFNX) is also needed. Ross (1970) suggests a value of BFNX equal to GWS for a starter. Unless a large storm occurred within the last few days prior to October first, IFS and UZS will be zero. The lower zone (UZS) and groundwater (GWS) storages may be estimated by studying the water balance within the watershed for the entire or the latter part of the previous month (September). These may also be reasonably estimated by trial and error. It will normally take three or four computer runs before reasonable estimates are obtained. All of these initial moisture storages are expressed in average inches of moisture throughout the drainage area.

Other input data include the daily average streamflows and flow diversions in and out of the watershed in cubic feet per second. The daily recorded streamflows are optional inputs to the KWM but are required by the superimposed erosion model. Daily suspended sediment loads in tons are optional inputs to the erosion model and are used only for comparison with synthesized sediment loads.

Parameters Optimization

The long list of parameters required by the watershed model is an indication of the degree of difficulty new users encounter in attempting to use the model. Although most of these parameters can be readily found from hydrologic or meteorologic records and topographic maps, there are those that are not easily derived. The only way to estimate these parameters, apparently, is to relate them empirically to measurable watershed characteristics. This can only be achieved through the extensive use of the model hoping these parameters such as the basic maximum infiltration rate and seasonal infiltration adjustment constant can be consistently derived by different investigators. This appears plausible but, at present, the effort has barely started.

The Stanford group, being the first to develop a comprehensive watershed model, has also pioneered the search for parameter optimization techniques. Through parameter interactions and sensitivity studies, they were able to offer some guidelines and estimates which are invaluable to potential model users. Yet, the trial and error approach to estimating some of the more elusive parameters is still much a part of these guidelines. Such a calibration process is not only time consuming but also highly subjective. Different investigators may come up with substantially different sets of parameter values for the same data.

A pioneering effort at eliminating this trial and error approach has been made by James (1970) and Liou (1970). They developed a computerized procedure for selecting the optimum set of parameter values for the KWM in a consistent and objective manner. The self-calibrating version of the KWM (also called OPSET) which utilizes this procedure optimizes the selection of 13 watershed parameters. This self-calibrating model was tested on numerous small watersheds in Kentucky.

Considering the magnitude of the task, the results of the tests using OPSET are of course inconclusive and incomplete. Also, OPSET does not take into account snowmelt and, hence, is not applicable where appreciable runoff comes from snowmelt. Nevertheless, such an approach yields rough estimates of some parameters and appears to give promise of eventual success if sufficient effort were devoted toward its expansion (to include snowmelt among other things) and modification.

Appendix C lists some typical input data for the watershed model listed on Appendix A. The list also includes the input data required by the superimposed erosion model. The input data are for the Four Mile Creek watershed near Traer, Iowa. The values of the watershed parameters on the listing were estimated using OPSET as well as the guidelines given by Anderson and Crawford (1964) and Crawford and Linsley (1966).

CHAPTER IV. SHEET EROSION MODEL

Development of the Sheet Erosion Model

It was not until just recently that attempts have been made to study the physical phenomena involved in the soil erosion process. Although the mechanisms involved in the process have not changed and man's involvement in the problem of soil erosion dates back to the earliest recorded civilization, the fundamental mechanisms involved in the process are not yet fully understood. This may be partly due to the availability of practices and methods of coping with the problem. These methods have been developed by trial and error.

In spite of the availability of erosion control practices, the general field of soil erosion is of utmost importance for a variety of reasons. With the growing population and limited resources, modern society is undergoing a reordering of priorities. The control of streams, protection of the environment, roads, and hydraulic structures as well as the preservation of the landscape become necessary and feasible for modern society. There is an ever present need for the sound prediction of sheet and rill erosion from agricultural as well as urban watersheds.

It was pointed out in Chapter II that several empirical equations for predicting sheet and rill erosion have been proposed. These equations have been developed by correlating observed erosion rates from small experimental plots with the multitude of variables existing in these plots. As pointed out by James (1970), such equations have glaring weaknesses such as:

1. They are not comprehensive. The many possible variations in climate and watershed conditions are so great that it is impossible to develop a comprehensive correlation covering all types and gradations in variations. As a result, errors of the magnitude of 300 to 400 per cent are not uncommon with the use of such equations (Beer et al., 1966).

2. They are usually applicable on a yearly basis or longer. When assessed against the need for predicting instantaneous sediment loads in streams (i.e., fish and wildlife protection), such equations are of very little use.

3. They do not take advantage of the physical processes occurring within the watershed. Without the use of such information it is impossible to use them on large watershed complexes undergoing some modifications.

The above discussions point to the need for a sound physical model of the soil erosion process. It was pointed out in Chapter II that several mathematical models designed to serve as frameworks for quantitative soil erosion models have been proposed. Their possible applications are, however, hindered by the lack of reliable information on the overland flow components of the measured total river discharges.

The development of the digital watershed models that distinguish between the flow components which make up the total river discharge opens a new horizon in soil erosion research. Negev's (1967) exploratory study shows that an erosion model based on the analysis of the processes involved and currently available information shows eventual promise if sufficient efforts are directed toward this objective.

The major elements of the sheet and rill erosion model are shown on Figure 10. The model does not differentiate between sheet and rill erosion since there is no clearcut distinction between the two forms of erosion. Hence, they will be referred to as simply sheet erosion.

Precipitation, overland flows, and daily recorded streamflows are the major input data required. The overland flows are synthesized by the watershed model upon which the erosion model is superimposed. Daily recorded streamflows are used instead of the synthesized flows in order to minimize errors in estimating channel banks and bed scouring.

The erosion model computations begin with the first occurrence of rain or snowmelt. In the case of rain, the raindrops hitting the ground splash soil particles in all directions. The quantity of soil splashed will depend upon the impact force, watershed cover, land slope, wind direction, rainfall characteristics, and the depth of the water layer above the soil surface.

The water layer above the soil surface serves as a buffer zone against the impact of the raindrops. It is, therefore,

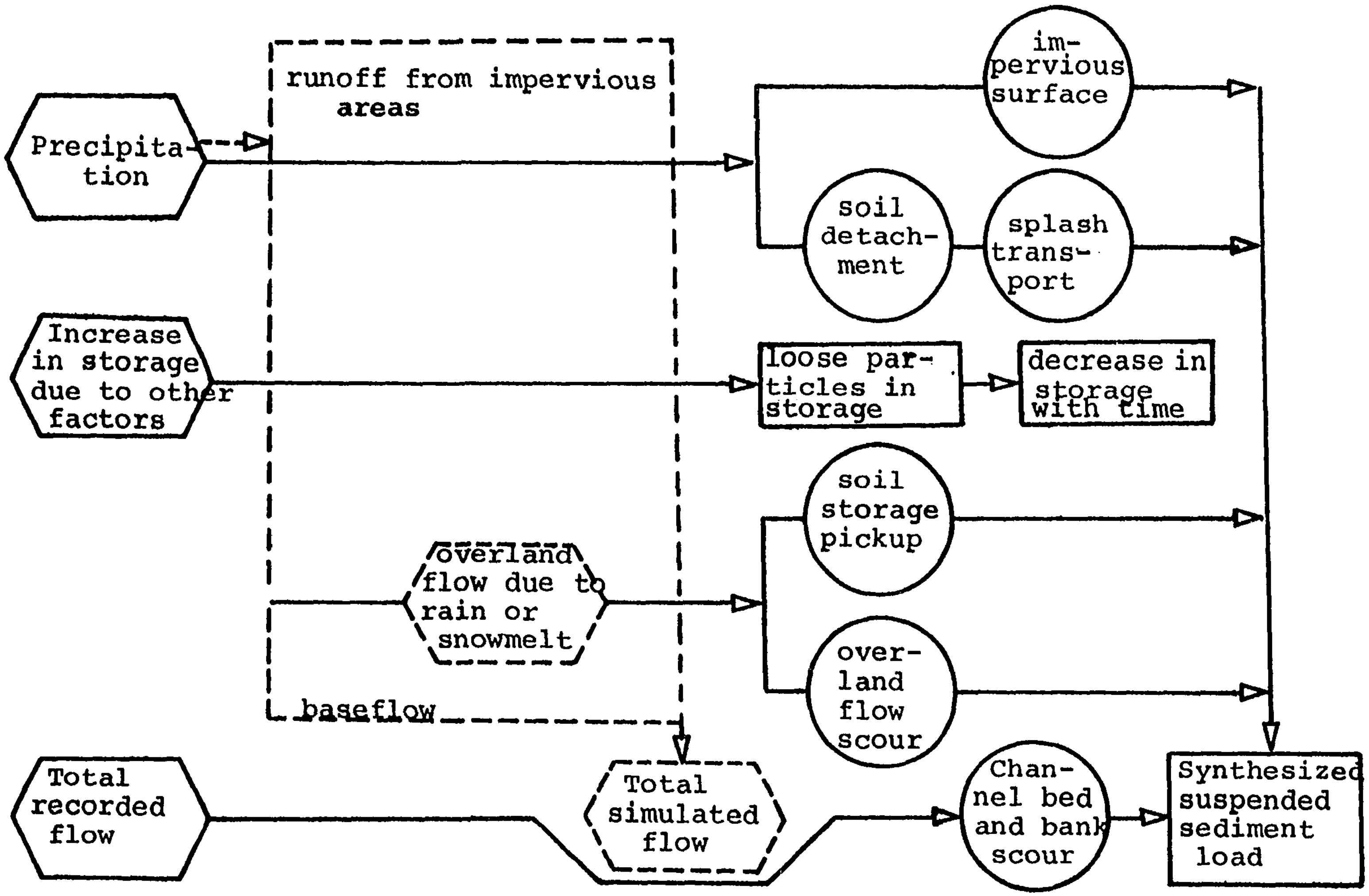


Figure 10. Flowchart of the sheet erosion model superimposed on the watershed model

reasonable to assume that the impact force decreases with the water depth. Similarly, the impact force decreases with the slope of the soil surface since the component force normal to the surface is a function of the cosine of the slope. Denser vegetal cover also reduces the impact force of the raindrops.

The individual influences of the above factors on the amount of soil splash are not well understood. At very low water depth, the buffering effect of the water film is offset by its lubricating effect on the individual soil particles. As the depth increases, this buffering effect becomes more pronounced. The effects of wind speed and land slope are similar in the sense that they both tend to decrease the component of the impact force normal to the surface. It must be noted, however, that while land slope tends to reduce the impact force it has an overall tendency to increase the erosion rates as a result of greater overland flow rates and soil splash transport downslope.

Numerous experimental studies have been conducted on splash erosion. Since under normal field conditions neither the drop velocity nor the drop diameter can be conveniently measured, most of these investigations were directed toward finding functional relationships among splash erosion, rainfall intensity, and kinetic energy. In a recent study Bubenzer and Jones (1970) estimated the quantity of soil splash from small plots by the following expression

$$SPLASH = A\ (KE)^{n}\ I^{m} \tag{4-1}$$

where

SPLASH = amount of soil splash

KE = kinetic energy of the raindrops

I = rainfall intensity

A = constant

n,m = exponents having ranges of 0.27 to 0.55 and 0.83 to 1.49, respectively

The kinetic energy of rain is estimated by Mihara (1951) as

$$KE = B\ I^{1.20} \tag{4-2}$$

where B is a soil constant. Combining Equations (4-1) and (4-2) gives

$$SPLASH = A\ B\ I^{m + 1.2n} \tag{4-3}$$

Bubenzer and Jones (1970) tabulated their experimental values of m and n for different soils. Their analysis shows mean values for all soils studied of 0.42 and 1.29 for m and n, respectively. Substituting these values in Equation (4-3) gives

$$SPLASH = A\ B\ I^{ALP1} \tag{4-4}$$

where ALP1 is approximately equal to two. It is interesting to note that this is the same relationship Meyer and Wischmeier (1969) obtained after carefully reviewing earlier research findings. In a recent study, Holy and Vitkova (1970) derived a relationship similar to Equation (4-3). Their study shows that the exponent (m + 1.2n) is a function of the land slope.

From the above considerations of the factors affecting the amount of soil splash it appears that the amount of soil splash for any given time interval may be expressed by the following equation

$$SPLASH = SC_F \; LS_F \; I^{ALP1} \exp(-k \; SPDR) \tag{4-5}$$

where

SC_F = soil and soil cover factor

LS_F = land slope factor

k = exponent greater than one

SPDR = the overland flow depth

On a flat surface the net transport of soil particles by raindrop impact will be zero. Otherwise, a portion of the soil splashed will be transported downslope. Ekern (1951) found that the net amount of soil transported downslope is directly proportional to the land slope. This amount is transported for a certain distance only and in the absence of overland flow to transport it further downslope only the particles splashed near the rills and waterways will find their ways into the streams. This amount of soil splashed directly into the waterways may be estimated as

$$SSPL = AR_d \; OFSS \; SPLASH \tag{4-6}$$

where

OFSS = average overland flow surface slope

AR_d = area representing the total land surface within a splashing distance to a stream surface

SSPL = the amount of soil splashed directly into the stream surfaces for any given time interval

By definition, detachment by rainfall is always greater than soil splash. The mechanisms involved in both processes are, however, the same. An expression of the amount of soil detached by rainfall may thus be obtained by multiplying the right hand side of Equation (4-5) by a constant. Such an expression is needed in estimating the amount of detachment storage at any given time.

The detached material that does not directly fall on a stream surface may be redeposited on the ground, on plant leaves and residues, or may remain in suspension and be transported downslope in case overland flow does occur. The relatively finer particles in suspension will find their ways into the streams while the coarser ones may be deposited at some points along the overland flow surface. The redeposited soil particles will be left loosely on the ground for some time as detachment storage. Upon the occurrence of the next overland flow, they may be picked up and added to the soil that is already being transported.

The detached particles in storage will eventually form aggregates with the shrinkage of the soil mass and the cementation of the clay particles and will no longer be available for overland flow pickup if left too long on the ground. The rate at which these loose particles form aggregates or the rate at which the detachment storage decreases with time will depend on the soil properties, moisture content, and climatic conditions. Higher values of soil aggregate formation may be expected during the spring and summer months when evapotranspiration rates are high. The rate at which the total detachment storage decreases can be approximated by the decay type function

$$\text{TSST} = \text{TSST}_o/\exp(\text{PWER Time}) \qquad (4\text{-}7)$$

where

TSST_o = total detachment storage at the beginning of the time interval

TSST = total detachment storage at the end of the time interval

PWER = ALP4/ALP5

ALP4 = soil factor

ALP5 = climate factor

Time = time interval

Soil detachment by rainfall may be controlled by vegetal cover, mulching, and cultivation practices. In addition, the amount of loose soil particles in storage may be drastically increased by alternate thawing and freezing, plowing, and earth moving operations. The influences of these factors are extremely difficult to evaluate quantitatively. Some of these are, however, more pronounced during the spring months while the canopy interception effects progressively increase as the growing season progresses. The effect of canopy cover may be approximated through the use of some crop growth indices such as the leaf area or the water use index.

A certain amount of scouring may also occur with overland flow. This will depend mostly on the stresses generated by the overland flow on the soil surface. The average shear stress on an overland flow plane may be approximated by

$$\tau_o = \gamma \text{ SPDR OFSS} \qquad (4\text{-}8)$$

where

τ_o = average shear stress on the overland flow plane

γ = specific weight of water

SPDR = depth of overland flow for the specific period

OFSS = overland flow surface slope

Equation (4-8) though valid only for small slopes ($\sin\theta = \theta$) gives stresses within the order of magnitude of those for greater slopes. On ideal conditions where overland flows occur as thin film flows over a uniformly smooth surface, the shear stresses associated with such flows even for very steep slopes are usually very small compared to the shear strength of cohesive soils. Under such conditions, only a very small amount of soil will be detached by overland flow and, hence, may be considered as negligible.

Overland flow under normal field conditions is usually concentrated along well defined paths or rills. Under such conditions, soil detachment by overland flow may be significant and may be estimated by the expression

$$\mathrm{SCROV} = \mathrm{BETA5}\ \mathrm{SPDR}^{\mathrm{BETA6}} \tag{4-9}$$

where

SCROV = amount of overland flow scour

BETA6 = an exponent

BETA5 = a constant representing the soil characteristics and the overland flow surface slope

The exponent BETA6 will be greater than or equal to one. Its value is equal to one under the idealized condition of flow of thin films. Where flow is concentrated along well defined rills such that the actual flow depth is greater than the average overland flow depth, SPDR, its value will be greater than one.

The ability of overland flow to transport the detached soil particles depends on the flow depth, flow velocity, and the land surface and soil characteristics. The overland flow velocity may be related to OFSS and SPDR by the following power function

$$\text{VELOVQ} = S_c \ \text{SPDR}^{\lambda_1} \ \text{OFSS}^{\lambda_2} \qquad (4\text{-}10)$$

where

VELOVQ = average velocity of overland flow

S_c = soil constant

λ_1 , λ_2 = exponents with values less than one.

Equation (4-10) is based on a well known equation (Manning's Equation) which is widely used in estimating the average velocity under turbulent flow conditions. Overland flow may well occur under both turbulent and laminar flow conditions. On the assumption that Equation (4-10) is valid, the transport capacity of overland flow may be expressed as

$$\text{TROVQ} = \text{SL}_F \ \text{OFSS}^{\delta} \text{SPDR}^{\text{ALP2}}$$

or simplifying the above expression further

$$\text{TROVQ} = \text{BETA3} \ \text{SPDR}^{\text{ALP2}} \qquad (4\text{-}11)$$

where

TROVQ = overland flow transport capacity

SL_F = soil and surface roughness factor

δ = an exponent

ALP2 = a constant

$BETA3 = SL_F \; OFSS^{\delta}$

Using Laursen's (1958) findings that the sediment carrying capacity of flowing water is approximately proportional to the fifth power of the flow velocity, VELOVQ, and Equation (4-10), Meyer and Wischmeier (1969) suggested that the exponents ALP2 and δ are both approximately equal to 1.67.

Equation (4-11) is a potential transport function and as such should be greater than or equal to the actual overland flow transport rate, ATROVQ. Thus the actual transport rate from storage is equal to TROVQ when TROVQ is less than TSST. Otherwise, TROVQ is equal to TSST.

Under normal field conditions, Equation (4-11) applies only to the unrilled sections of a watershed where the overland flow transport capacity is usually the limiting factor to sediment movement. This equation uses average values for overland flow depth, SPDR, and land slope OFSS which are representative of the flow conditions in the unrilled areas of the watershed since these areas represent a very large fraction of the total watershed area.

Overland flow scouring usually occurs in significant amount only in the rilled areas of the watershed where flow converges on steeper overland flow slopes. The combination of these two factors results in greatly increased transport capacity which is not reflected in Equation (4-11). Under such condition, the overland flow transport capacity is not a limiting factor to sediment movement. Hence, the overland flow scouring phenomenon as expressed by Equation (4-9) is treated independently of Equation (4-11).

The amount of soil particles picked up from impervious areas will be influenced by the same factors affecting soil splash. Since this amount constitutes only a small portion of the total sheet erosion from agricultural watersheds, it may be conveniently approximated as

$$IMPU = KP\ FIMP\ SPLASH \tag{4-12}$$

where

IMPU = amount of sediments picked up from impervious areas

KP = empirical constant

FIMP = fraction of the watershed being impervious

Upon entering the waterways, the finer particles may remain in suspension and be transported downstream. The coarser particles may be deposited, roll, or bounce along the bed. Along with the deposition of the eroded particles, channel bed and bank scouring may simultaneously be occurring. Factors affecting the equilibrium quantities between deposition and scouring are the fall velocities of the particles and the transporting and scouring abilities of the streamflow.

The mechanics of sediment transport by streams are not well understood. There are no reliable theories concerning the suspended or bed load discharges of streams and the currently available equations are largely empirical in nature. Progress is being made, however, on the mechanics of sediment suspension and this phase of the problem is relatively well understood. This progress is greatly enhanced by the development of the modern concepts of turbulent flow. Unfortunately, however, theoretical considerations while being confirmed in small laboratory flume experiments, do not check very well with the actual stream data. Furthermore, the application of these theoretical equations requires the estimation of certain parameters which are not normally known Raudkivi , 1967; Vanoni *et al.*, 1960).

For small agricultural watersheds where gully and larger rill erosion contributions are relatively small, it could be reasonably assumed that most of the eroded soil particles are relatively finer and will remain in suspension and, hence, will be transported as wash load. This implies that the eroded soil particles will move through the system in single runoff event. This assumption may not be valid where there are drastic changes in the slope, soil shear stresses, or overland flow surface roughness. Under such conditions, deposition usually occurs at the base of the slopes where the shear stresses and flow resistance change.

The scouring of the channel banks and bottom may contribute to the sediment load significantly especially in case of larger floods. This contribution to the total suspended sediment load is difficult to estimate. A portion of sediment scoured from bed and banks of channels may occur alternately as bed load or interload. A review of the better known bed load and interload formulas showed that errors involved of magnitudes of 100 per cent or more are to be expected from their uses and that it is not possible to recommend any formula or formulas (Vanoni *et al.*, 1960).

In view of the imperfect state of the theories of sediment transportation, the estimation of the portion of the sediment load coming from channel banks and bed scouring must rely on an empirical approach. A practical objective then is to obtain an empirical equation in terms of the relevant hydraulic parameters and sediment properties. Such equation may be of the form

$$SCOUR = f(Y, V, ds, n, S, \gamma d)$$

where

SCOUR = channel bed and bank scouring

Y = flow depth in channel

S = channel grade

V = average velocity of flow

n = channel roughness coefficient

ds = mean sediment diameter

γd = specific weight of sediments

For a given stream, Y, V, and S are related to the discharge, DRSF. The remaining parameters, for simplicity, may be represented by a single parameter, BETA4. Thus

$$\text{SCOUR} = \text{BETA4 DRSF}^{\text{ALP3}} \tag{4-13}$$

where ALP3 is an exponent. In the above equation DRSF is the mean daily discharge and, hence, the equation applies on a daily basis only.

For a specific period, the total amount of sheet erosion is the sum of the various sheet erosion components. This total amount is given by

$$\text{USFA} = \text{ATROVQ} + \text{SCROV} + \text{SSPL} + \text{IMPU} \tag{4-14}$$

where

USFA = total sheet erosion rate for the specific period

ATROVQ= TROVQ; TROVQ $\leq$ TSST

= TSST; TROVQ > TSST

and the rest of the terms are as previously defined. Substituting Equations (4-5), (4-6), and (4-12) into Equation (4-14) yields

$$\text{USFA} = \text{ATROVQ} + \text{SCROV} + (\text{AR}_d\ \text{OFSS} + \text{KP FIMP})\ \text{SC}_F\ \text{LS}_F \times \exp(-k\ \text{SPDR})\ \text{I}^{\text{ALP1}}$$

or simplifying further

$$USFA = ATROVQ + SCROV + SSPLH \tag{4-15a}$$

where

$$SSPLH = BETA1\ SPIX$$

$$BETA1 = (AR_d\ OFSS + KP\ FIMP)\,SC_F\ LS_F\ \exp(-k\ SPDR) \tag{4-15b}$$

$$SPIX = I^{ALP1}$$

In the model a single parameter, BETA1, is used to represent the combined effect of the different watershed variables used in deriving Equation (4-15b). The use of single parameter to represent these variables may be justified by the fact that the sheet erosion components SSPL and IMPU usually represent only a small portion of the total sheet erosion, USFA. Also, under field conditions the effect of the depth of overland flow on the raindrops impact is usually small except in areas where there are numerous shallow depressions. Furthermore, in view of the fact that the average overland flow slope for the entire watershed cannot be accurately estimated, the effect of OFSS cannot be properly evaluated unless several watersheds with sharply contrasting OFSS values are modeled. Such a job requires a great deal of effort and computer time.

The daily synthesized suspended sediment load is computed as

$$TDSSL = SCOUR + DSSE \tag{4-16}$$

where

TDSSL = total daily synthesized suspended sediment load

DSSE = summation of USFA over the 24-hour period

Operation of the Sheet Erosion Model

Figure 11 shows the schematic diagram of the proposed sheet erosion model as based on Equations (4-15a) and (4-16). A simplified loose soil particles accounting procedure is used by the model. First, the soil splash index is calculated for the specific period. This index is then used to estimate the soil detachment storage, SSTO, for the same period using the expression

$$SSTO = BETA2\ REDX\ SPIX \tag{4-17}$$

where

BETA2 = a watershed constant

REDX = an index to the reduction in rainfall energy as a result of the changes in the vegetal cover and the form of precipitation.

When the precipitation is in the form of rain, REDX is approximated by a vegetation water use index. If the soil is bare, REDX is set equal to one. During the crop growing season, it is reduced in proportion to ratio of the current potential water use of the vegetation to the maximum potential water use at the peak of the vegetal growth. When precipitation is in the form of snow, REDX is set equal to zero.

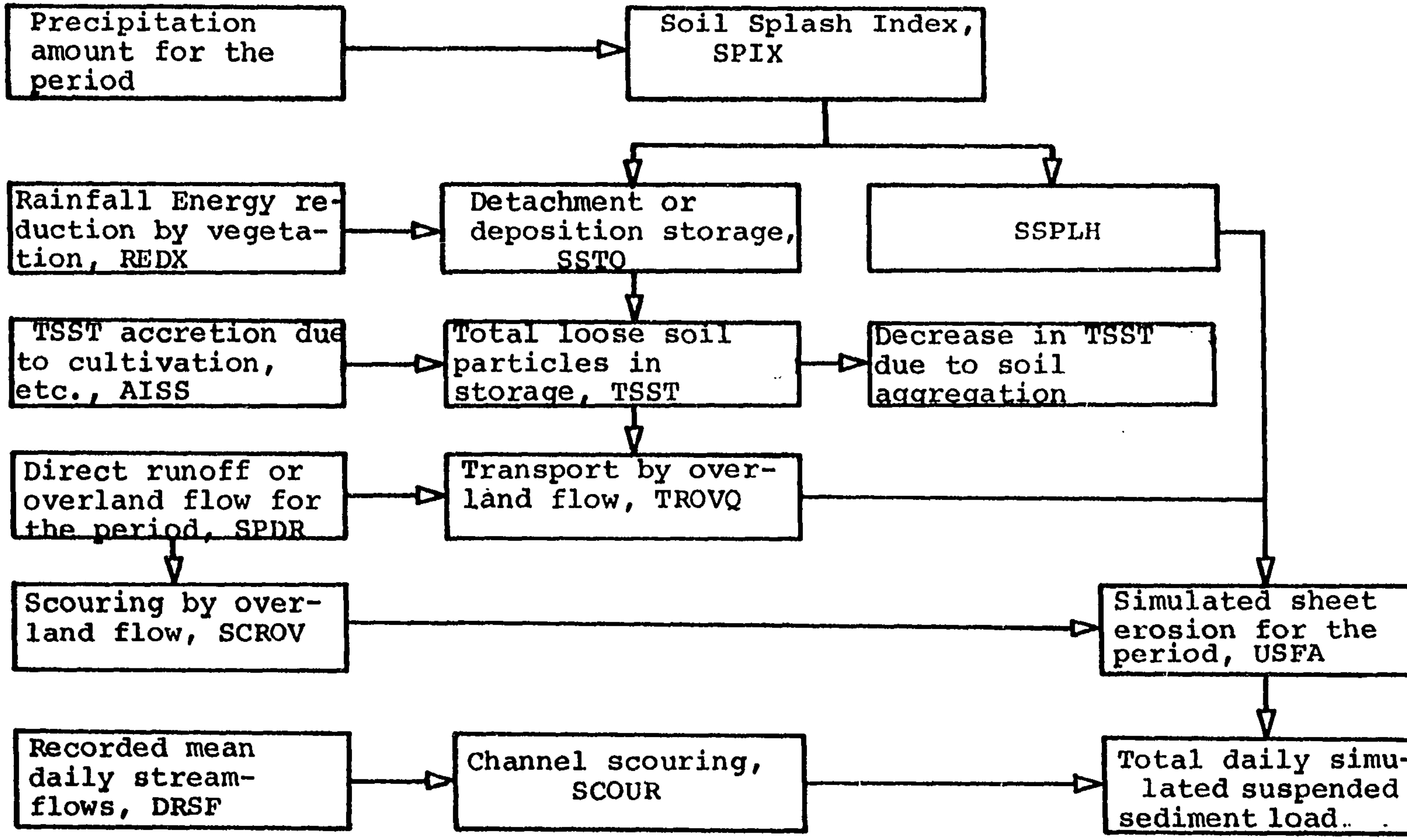


Figure 11. Schematic diagram of the proposed sheet erosion model

The estimated soil detachment storage, SSTO, is added to the loose particles in storage at the beginning of the period to obtain the current value of TSST. Accretions to TSST due to sources other than rainfall detachment are also added to TSST on the approximate day they occurred. The total soil particles storage is in turn continuously being depleted by overland flow transportation and soil aggregates formation.

The program listing for the sheet erosion model is given in Appendix A. This program which includes both the watershed and the sheet erosion models has been run on an IBM 360/65 computer. For a year of data the computer execution time is about 35 seconds.

Inputs and outputs The input data required by the sheet erosion model include the following:

1. Mean daily recorded streamflows. These are used to estimate the daily amounts of suspended sediments coming from channel banks and bed scouring. The principal sources of information for these data are the U.S. Geological Survey Surface Water Records.

2. Daily recorded suspended sediment loads. These are needed for statistical comparisons with the synthesized values. When such comparison are not required or such information are not available, an option is available for excluding them from the analysis. The usual sources of information on suspended sediment loads are the U.S. Geological Survey Water Quality Records.

3. A group of constants representing watershed parameters.

4. Hourly rainfalls and hourly or quarter-hourly overland flows.

The hourly rainfalls are also required by the watershed model in order to synthesize the overland flows.

The output from the model consists of the daily printouts of the computed sheet erosion, channel scouring, and suspended sediment loads. An option is also available to print out the recorded suspended sediment loads. A sample of inputs to the program is given in Appendix C. A summary of the various input and output variables is given in Table 1.

Table 1. Summary of the input and output variables for the sheet erosion model

Variable	Type R=real I=integer	Dimension	Unit	Definition
DRSF	R	366	cfs	Average daily recorded streamflows
DRSL	R	366	tons	Daily recorded suspended sediment loads
DRHP	R	366,24	inches	Dated recorded hourly precipitation
ALP1	R	1	-	See Equation (4-4)
ALP2	R	1	-	See Equation (4-11)
ALP3	R	1	-	See Equation (4-13)
ALP4	R	1	-	See Equation (4-7)
ALP5	R	1	-	See Equation (4-7)
	I	1	-	Days of the water year which are used as
KDAY1	I	1		indices to change the value of ALP5 as
KDAY2	I	1	-	a result fo the seasonal variations in climate
BETA1	R	1	-	See Equation (4-15b)
BETA2	R	1	-	See Equation (4-17)
BETA3	R	1	-	See Equation (4-11)
BETA4	R	1	-	See Equation (4-13)
BETA5	R	1	-	See Equation (4-9)
BETA6	R	1	-	See Equation (4-9)
AISS	R	1	tons	Amounts of accretion in total loose particles storage other than those due to raindrop splash
ISST1	I	1	-	Approximate dates accretions in storage of
ISST2	I	1	-	the amount AISS take place
DSSE	R	366	tons	Daily synthesized sheet erosion
SCOUR	R	366	tons	Daily amounts of channel bed and banks scouring
DSSL	R	366	tons	Daily synthesized suspended sediment loads

CHAPTER V. SIMULATION RESULTS -- FOUR MILE CREEK WATERSHED NEAR TRAER, IOWA

This chapter describes the application of the sheet erosion model to the Four Mile Creek watershed near Traer, Iowa. Figure 12 shows the map of the watershed. A brief description of the watershed is given below. This description also includes a summary of the hydrological characteristics related to this study as well as a list of the records used in the simulation study.

Description of the Watershed

Location: Tama County, Iowa. The center of the watershed is about 7 miles northwest of Traer, Iowa (see Figure 13)

Area: 19.51 square miles

Average Annual Rainfall: 32.5 inches

Average Annual Runoff: 10.6 cfs or 7.38 inches per year (based on 9 years of records)

Vegetal cover: Mostly row crops and meadow, small grains in small fields.

Soil type: Silt loam, moderate to thick in depth, loess-derived.

Summary of Available Records:

Runoff: October, 1962 to date. Maximum and minimum discharges recorded are 628.0 and 0.2 cfs, respectively. Records are good except for those for the winter period which are poor. (Source: U.S. Geological Survey)

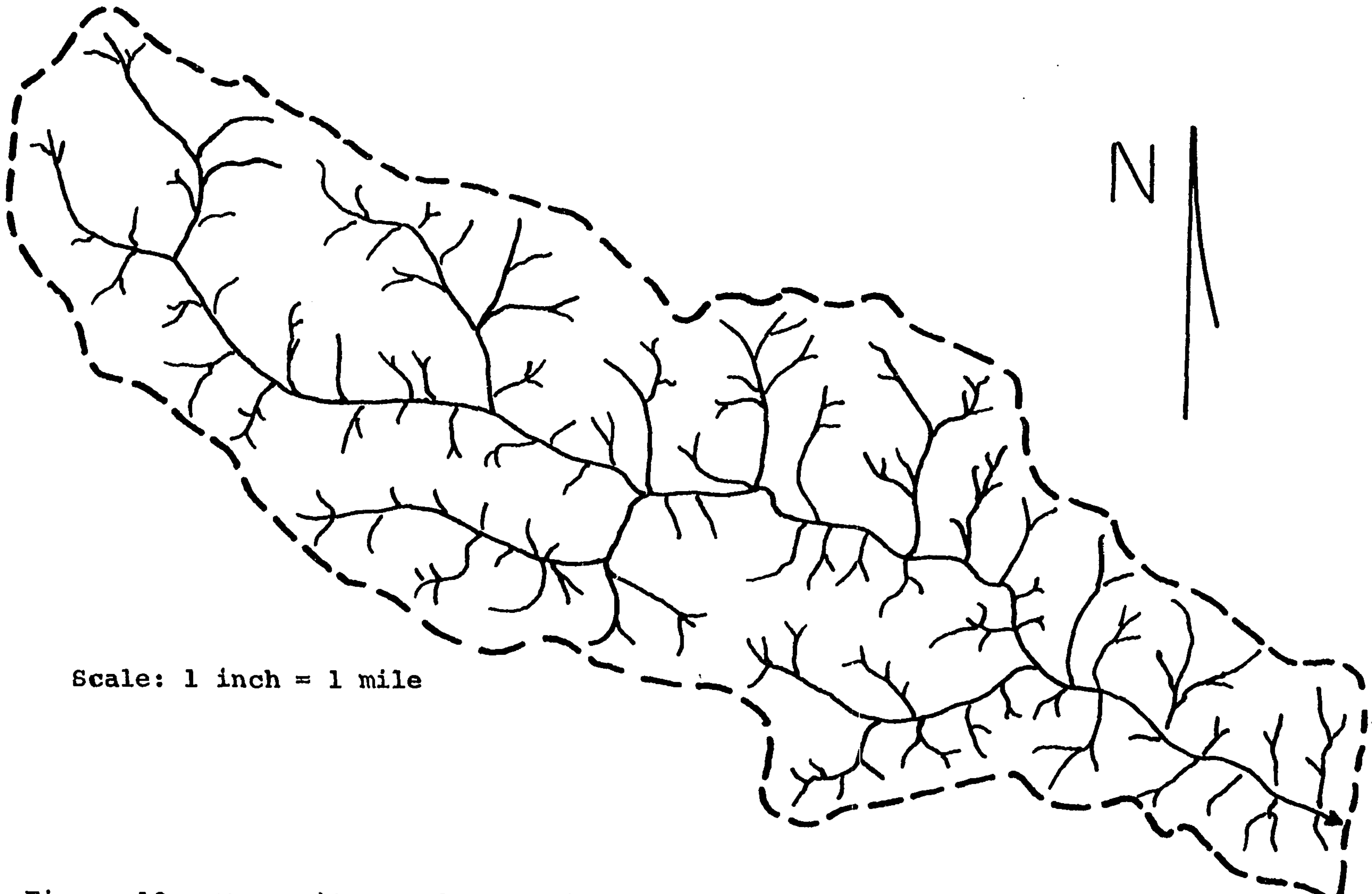


Figure 12. Four Mile Creek watershed near Traer, Iowa

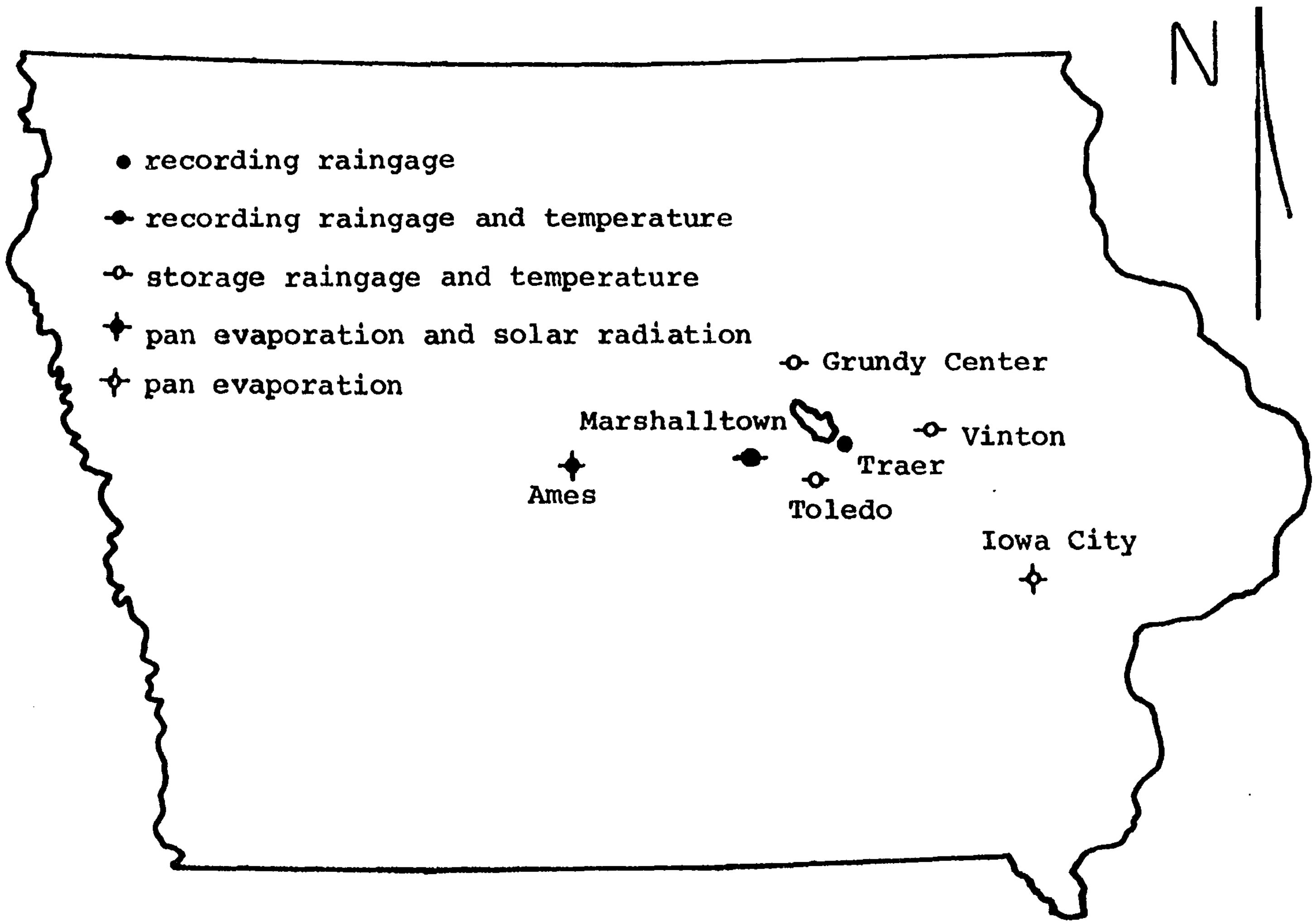


Figure 13. Location of the watershed and the sources of climatological information

Rainfall: Recording raingage at Traer, Iowa. Measurements date back prior to 1962 and continuing at present. (Source: U.S. Weather Bureau)

Sediment: Daily suspended loads from October, 1969 to date. (Source: U.S. Geological Survey)

Evaporation: The nearest stations with pan evaporation records are those located at Ames and Iowa City. Measurements date back prior to 1962 and continuing at present. (Source: U.S. Weather Bureau)

Solar radiation: The nearest measuring station is located at Ames, Iowa. Measurements date back prior to 1962 and continuing at present. (Source: U.S. Weather Bureau)

Temperature: Minimum and maximum temperature data are measured at nearby stations as shown on Figure 13. These stations are located at Grundy Center, Marshalltown, Toledo, and Vinton. The annual mean temperature for the watershed is about 48°F. (Source: U.S. Weather Bureau)

Streamflow Simulation Results

The first step in the suspended sediment load simulation procedure is the application of modified Kentucky Watershed Model to the watershed. The watershed parameters were estimated using the guidelines suggested in Chapter III. The possible application of the self-calibrating version (OPSET) of the Stanford Watershed Model in estimating some of the watershed parameters was first explored.

The three water years starting from 1963 through 1965 were used to evaluate the feasibility of using OPSET. The results were inconclusive as a result of the shortcomings of

OPSET as mentioned in Chapter III. Furthermore, the OPSET Fortran programs have not yet been fully debugged and they did not work satisfactorily for two of the three water years. Consequently, the use of OPSET was abandoned because of the enormous amount of time needed to modify and debug it. One water year of calibration using OPSET costs 50 dollars or more. A corresponding computer run using the Kentucky Watershed Model costs approximately four dollars. The watershed parameters that cannot be measured directly were, therefore, estimated by fitting or trial and error.

The watershed model was calibrated using the 1969 and 1970 water years. In the calibration process, more emphasis was given to the 1970 water year since this was also the same water year for which the sheet erosion model was to be calibrated. Only a few calibration runs were made using the 1969 water year. The 1971 water year was used as a test water year for both the watershed and the erosion models.

The best estimates of the Four Mile Creek watershed parameters are listed on Table 2. In addition to these parameters, estimates must also be made of the ratios of evapotranspiration to pan evaporation at various periods throughout the water year. These ratios were estimated using the research findings of Denmead and Shaw (1959) and Shaw (1963). These ratios as shown on Table 3 were estimated using the corn crop as the standard since it is the predominant crop

Table 2. Estimated watershed parameters for Four Mile Creek area near Traer, Iowa

Parameter	Value	Parameter	Value	Parameter	Value
BDDFSM	0.0008	FIMP	0.025	OFSS	0.05
SPBFLW	0.05	FWTR	0.000	CHCAP	350.0
SPTWCC	0.25	VINTMR	0.15	OFMN	0.038
SPM	1.15	BUZC	1.00	OFMNIS	0.150
ELDIF	0.00	SUZC	1.70	IFRC	0.35
XNDFS	0.10	LZC	12.00	CSRX	0.98
FFOR	0.00	ETLF	0.30	FSRX	0.98
FFSI	0.10	SUBWF	0.00	EXQPV	0.20
MRNSM	0.12	GWETF	0.10	BFNLR	1.000
DSMGH	0.00	SIAC	2.00	BFRC	0.973
PXCSA	0.05	BMTR	8.00	GFIE	5.0
RGPMB	1.00	BIVF	0.00	NDTUZ	75
AREA	19.51	OFSL	600.0		

within the watershed. Instead of being used as variable inputs into the watershed model, these ratios are incorporated into the computer programs (MAIN0333-0340) as they are constants within the watershed for all the water years studied. They must be modified, however, if the watershed model is to be used in places where the climate and the cropping patterns are different from those existing within

Table 3. Ratio of evapotranspiration to pan evaporation throughout the water year[a]

Period during the water year[b]	Ratio	Period during the water year	Ratio
From day 1 through 150	0.35	From day 228 through 243	0.71
From day 151 through 165	0.41	From day 244 through 265	0.61
From day 166 through 181	0.47	From day 266 through 365	0.35
From day 182 through 196	0.67	Day 366	0.35
From day 197 through 227	0.80		

[a]For the period from day 1 through 150 and from day 266 through 366 a constant ratio was assumed. For the winter period where the ground is frozen and/or there is snow on the ground this ratio is not used as snow evaporation estimates are used instead.

[b]January 1 = day 1
December 31 = day 365
February 29 = day 366.

the watershed.

The ordinates of the time-area histogram estimated for the watershed are given on Table 4. These estimates are based on the following equation for the time of concentration

$$T_c = 0.0078\, L^{0.77}\, S^{-0.385} \qquad (5\text{-}1)$$

where

T_c = time of concentration in minutes

L = maximum horizontal length of flow measured along the stream in feet

S = slope in feet per foot or the difference in elevation between the outlet and the most remote point divided by the length, L.

Table 4. Time-area histogram for the Four Mile Creek Watershed near Traer, Iowa

Travel time in minutes	Area ratio	Travel time in minutes	Area ratio	Travel time in minutes	Area ratio
0		135		270	
	0.0094		0.0502		0.0536
15		150		285	
	0.0231		0.0587		0.0613
30		165		300	
	0.0288		0.0438		0.0434
45		180		315	
	0.0202		0.0373		0.0367
60		195		330	
	0.0239		0.0344		0.0300
75		210		345	
	0.0322		0.0442		0.0373
90		225		360	
	0.0283		0.0540		0.0352
105		240		375	
	0.0373		0.0460		0.0296
120		255		390	
	0.0370		0.513		0.0128
135		270		405	

Figure 14 shows the comparisons between the simulated and recorded average daily streamflows for the calibration water year of 1970 while those for the test water year of 1971 are shown on Figure 15. Table 5 shows the monthly and annual simulated and recorded streamflows for the water years from 1969 through 1971. The daily simulated and recorded streamflow values are tabulated on Appendix D.

From Figures 14 and 15 it is seen that the highest peaks are due to snowmelt. The watershed model tends to oversynthesize the snowmelt runoff peaks. As a result, the small streamflows are slightly undersynthesized so as to balance the incoming and outgoing moisture supply. These results indicate the need for a more comprehensive snowmelt subroutine. There are, however, serious limitations to any attempt to accomplish such a task. The major one is the scarcity of climatological data such as incident solar radiation.

Another limitation to any serious attempt at snowmelt modeling is the absence of factual information on the parameters governing snowmelt. Furthermore, the quality of the streamflow records are poor during the winter period as a result of the ice effect on the flow measurement. For this reason, no serious attempt has been made to develop a comprehensive snowmelt subroutine in this study.

The simulated streamflow values for the months of August and September are slightly higher than the recorded flows. Since these are low flow months, the discrepancies between

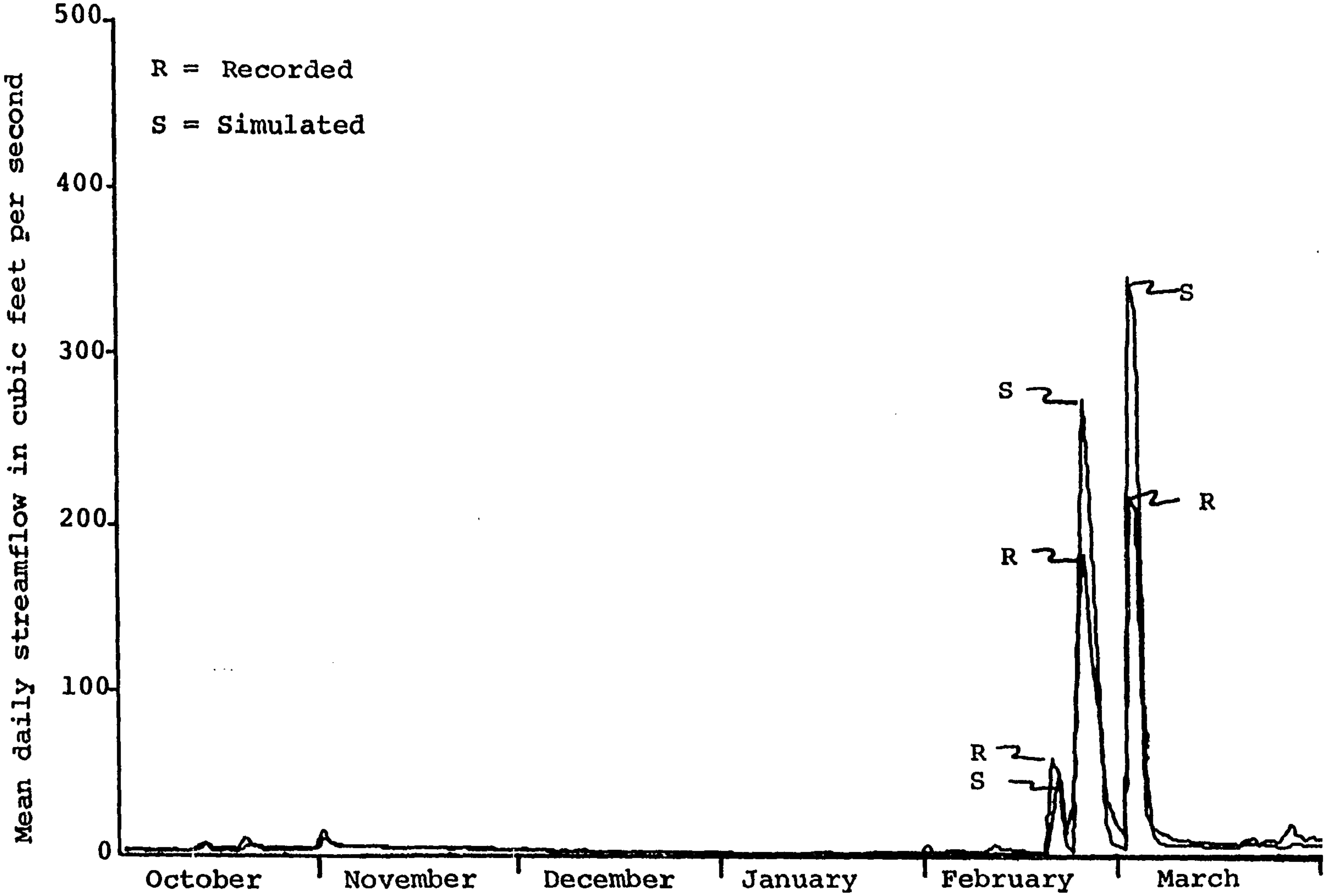
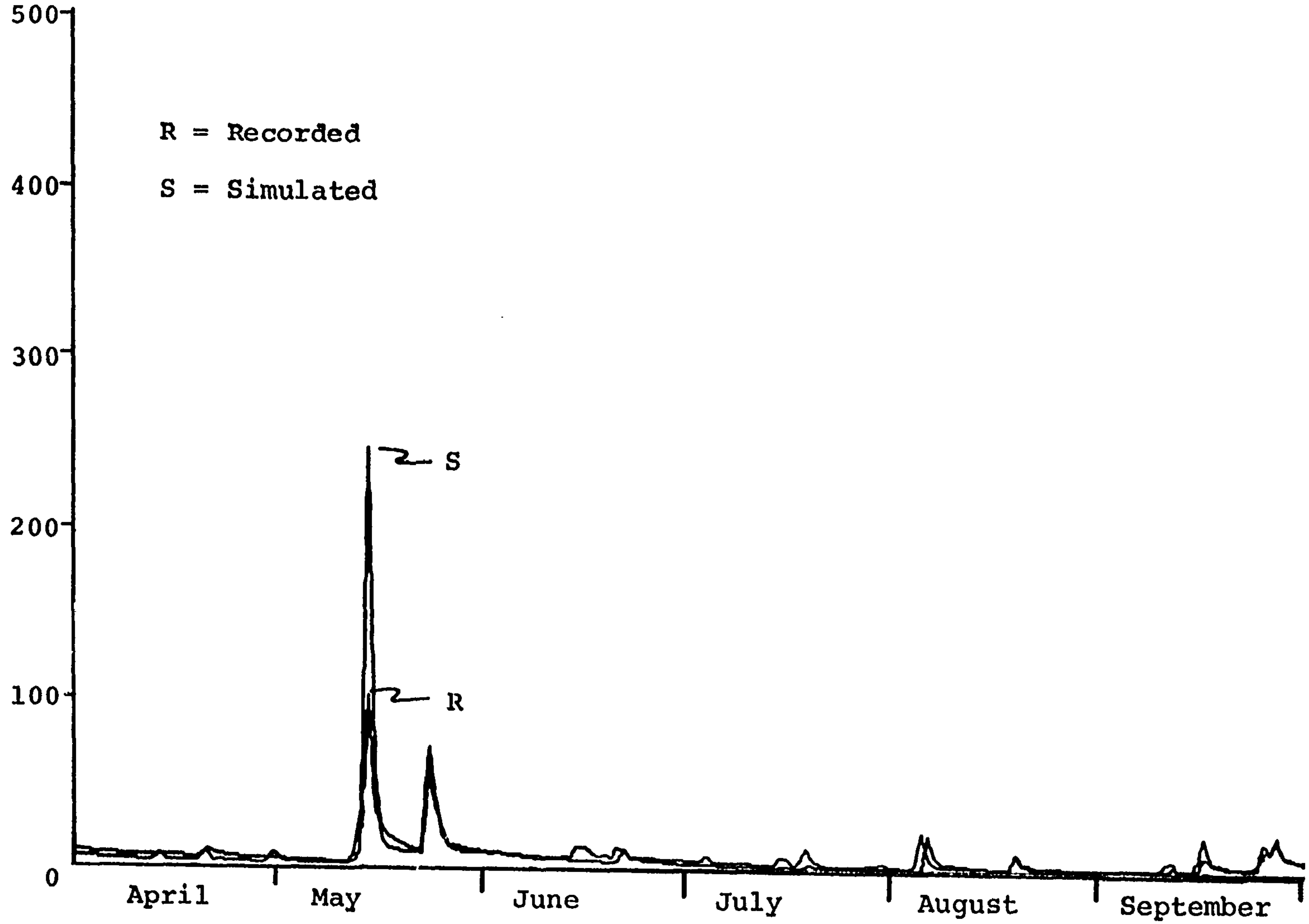


Figure 14. Mean daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year



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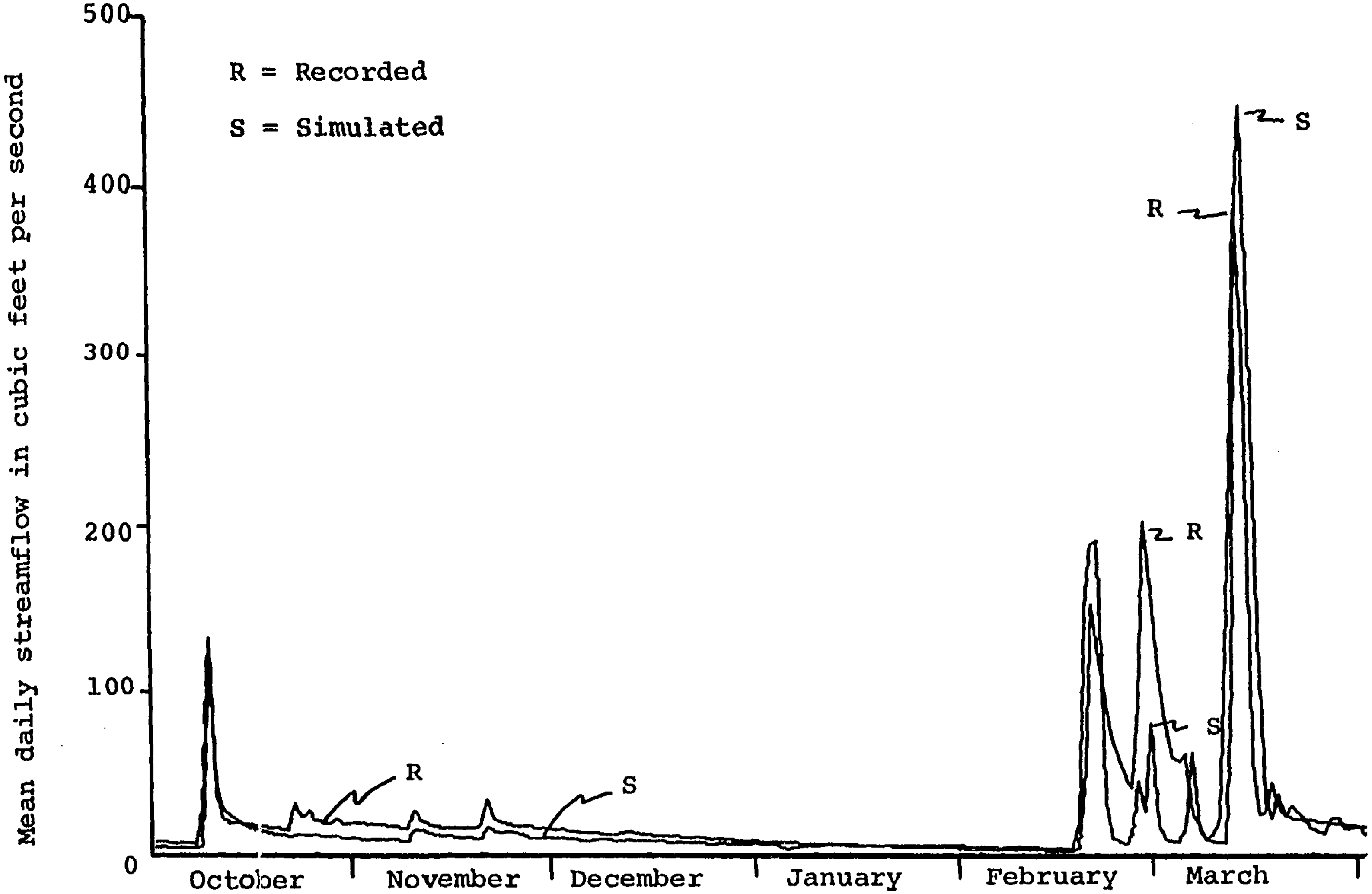

Figure 15. Mean daily recorded and simulated streamflow for the Four Mile Creek watershed near Traer, Iowa for the 1971 water year

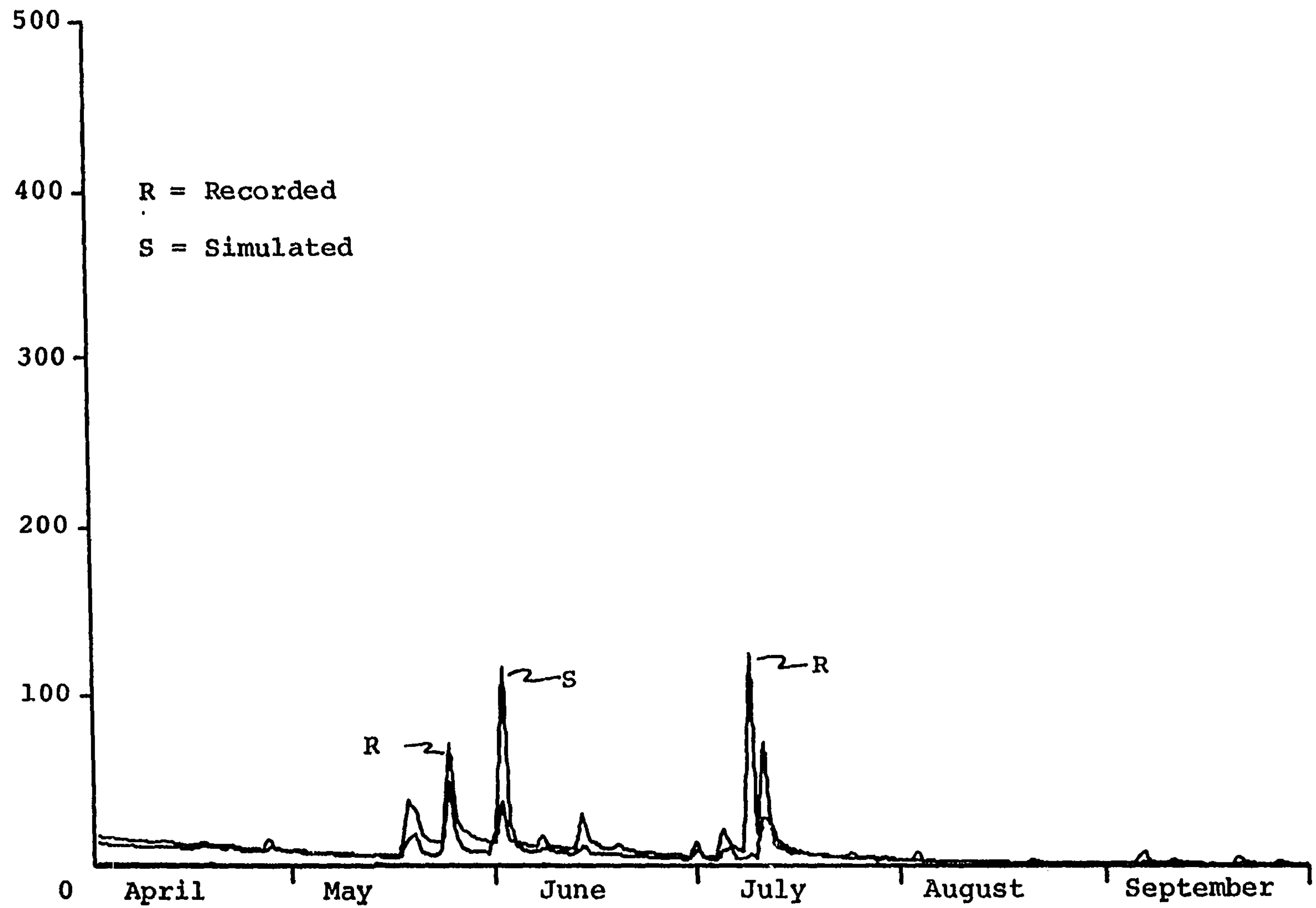

Figure 15 (Continued)

Table 5. Monthly and annual recorded and simulated streamflows for Four Mile Creek watershed near Traer, Iowa

Month	Water year 1969 Streamflow, cfs days		Water year 1970 Streamflow, cfs days		Water year 1971 Streamflow, cfs days	
	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated
October	213.3	336.0	118.1	117.3	494.4	657.6
November	101.7	260.4	124.9	122.0	328.8	540.7
December	300.0	451.0	68.6	59.9	238.6	340.7
January	283.6	136.0	48.0	34.5	159.7	160.1
February	238.6	157.6	807.4	843.0	1,143.0	797.6
March	1,778.7	961.4	721.7	910.5	1,896.0	1,848.8
April	1,067.0	1,448.0	216.8	152.7	262.7	334.0
May	878.0	1,406.0	516.2	654.4	408.9	267.7
June	1,363.0	1,013.7	183.1	252.8	322.7	322.4
July	1,979.8	1,327.4	53.1	129.6	417.2	217.0
August	432.3	509.5	92.0	85.1	40.3	59.9
September	130.0	207.4	140.0	159.1	16.6	39.8
Total	8,766.0	8,216.2	3,089.9	3,521.1	5,728.9	5,586.3
Daily Correlation Coefficient	0.68		0.96		0.76	

the simulated and recorded streamflows are insignificant when compared to the streamflows for the rest of the months within the water year. In general, the simulated average daily streamflows compared quite favorably with the recorded flow values for the 1970 and 1971 water years. Although the daily correlation coefficient for the 1969 water year is quite low, the monthly and annual simulated streamflows are comparable to the recorded values.

Aside from the errors inherent in the watershed model itself, the input climatological data are also sources of errors in the simulation of streamflows. For the Four Mile Creek watershed, the pan evaporation values were estimated by averaging the measured values from the measuring stations at Ames and Iowa City (see Figure 13). The estimates of the incident solar radiation were also based on the recorded values for Ames, Iowa.

The hourly rainfalls used were those recorded at Traer, Iowa which is about 7.5 miles from the center of the watershed. The variations in the rainfall amounts representative of the watershed and those measured at the recording gage at Traer, Iowa have been studied by Ruhe and Vreeken (1969). Their study showed that during the period from January 1, 1963 through March 31, 1967, precipitation was recorded 367 times on the Traer region. Rain was recorded 30 times at a storage raingage in the watershed but not at the Traer station and was recorded 48 times at the Traer station but not at the storage gage in the watershed. The two raingages are only about 4.5 miles away from each other. Additional yearly rainfall amounts recorded at the Traer station but not at the gage in the watershed are 0.73 in 1963, 0.61 in 1964, 0.89 in 1965, and 0.41 in 1966. From these figures it is obvious that there are also significant variations in the rainfall intensities and distributions between the two stations.

Results of Simulation of Suspended Sediment

The sheet erosion model was calibrated by trial and error using the 1970 water year. The best estimates of the sheet erosion model parameters are given in Table 6. The calibrated sheet erosion model was then tested on the test water year of 1971. Since only two water years of suspended sediment records are available, the calibration as well as testing of the sheet erosion model on two or more water years is not possible on Four Mile Creek watershed. Such extensive calibration and testing of the sheet erosion model, though feasible for other watersheds, has not been attempted because of prohibitive costs in terms of data collection and computer execution time.

Figure 16 shows the simulated and recorded daily suspended sediment loads for the calibration water year of 1970 while those for the test water year of 1971 are shown on Figure 17.

Table 6. Estimated sheet erosion parameters for the Four Mile Creek watershed near Traer, Iowa

Parameter	Value	Parameter	Value
ALP1	2.00	KDAY1	70
ALP2	1.50	KDAY2	360
ALP3	1.33	BETA1	20.0
ALP4	0.02	BETA2	625.0
ALP5	80.0	BETA3	833.0
ISST1	61	BETA4	0.150
ISST2	400	BETA5	41,600.0
AISS	3120.0	BETA6	3.50

Table 7 gives the monthly and annual simulated and recorded suspended sediment loads for both water years.

The two main sources of suspended sediment loads are sheet erosion and channel scour. These components as computed by the sheet erosion model are compared in Figure 18 which shows the daily simulated sheet and channel scour erosion rates for the 1970 water year. Similar data for the test water year of 1971 are shown on Figure 19. Table 8 shows the simulated monthly and annual sheet and scour erosion rates for both water years. The daily, monthly, and annual simulated and recorded sediment loads are shown in Appendix E.

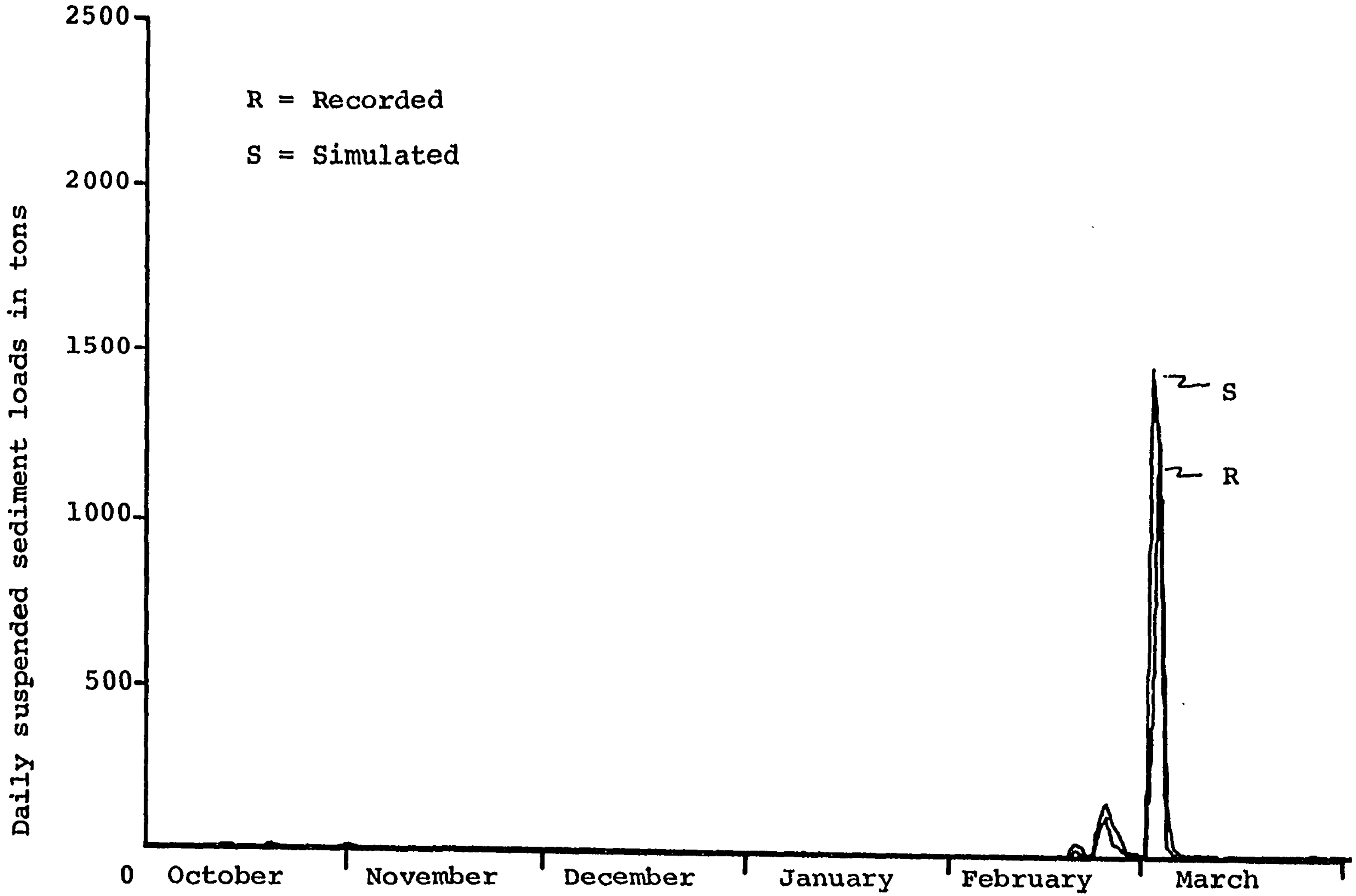

Figure 16. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year

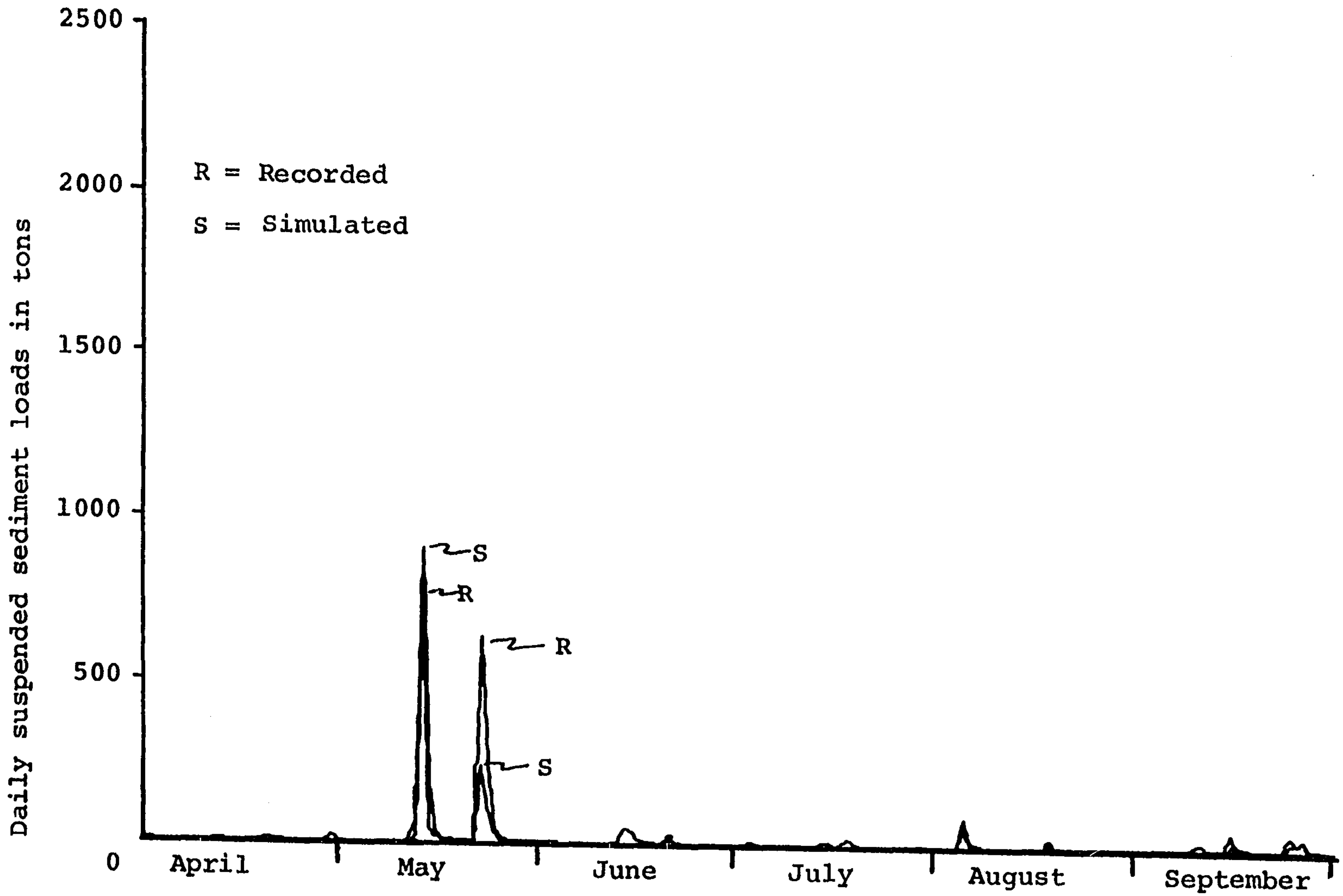

Figure 16 (Continued)

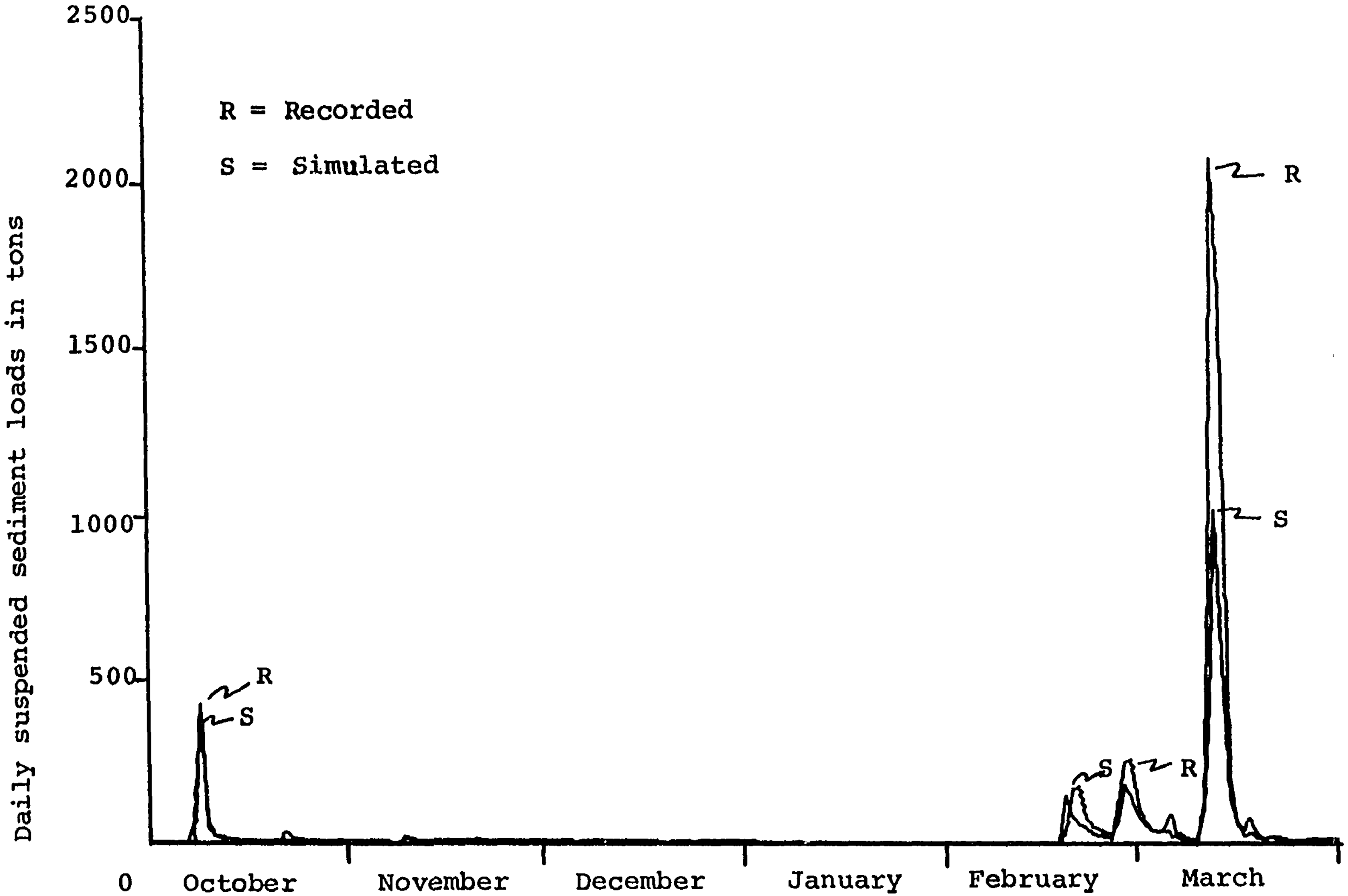

Figure 17. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1971 water year

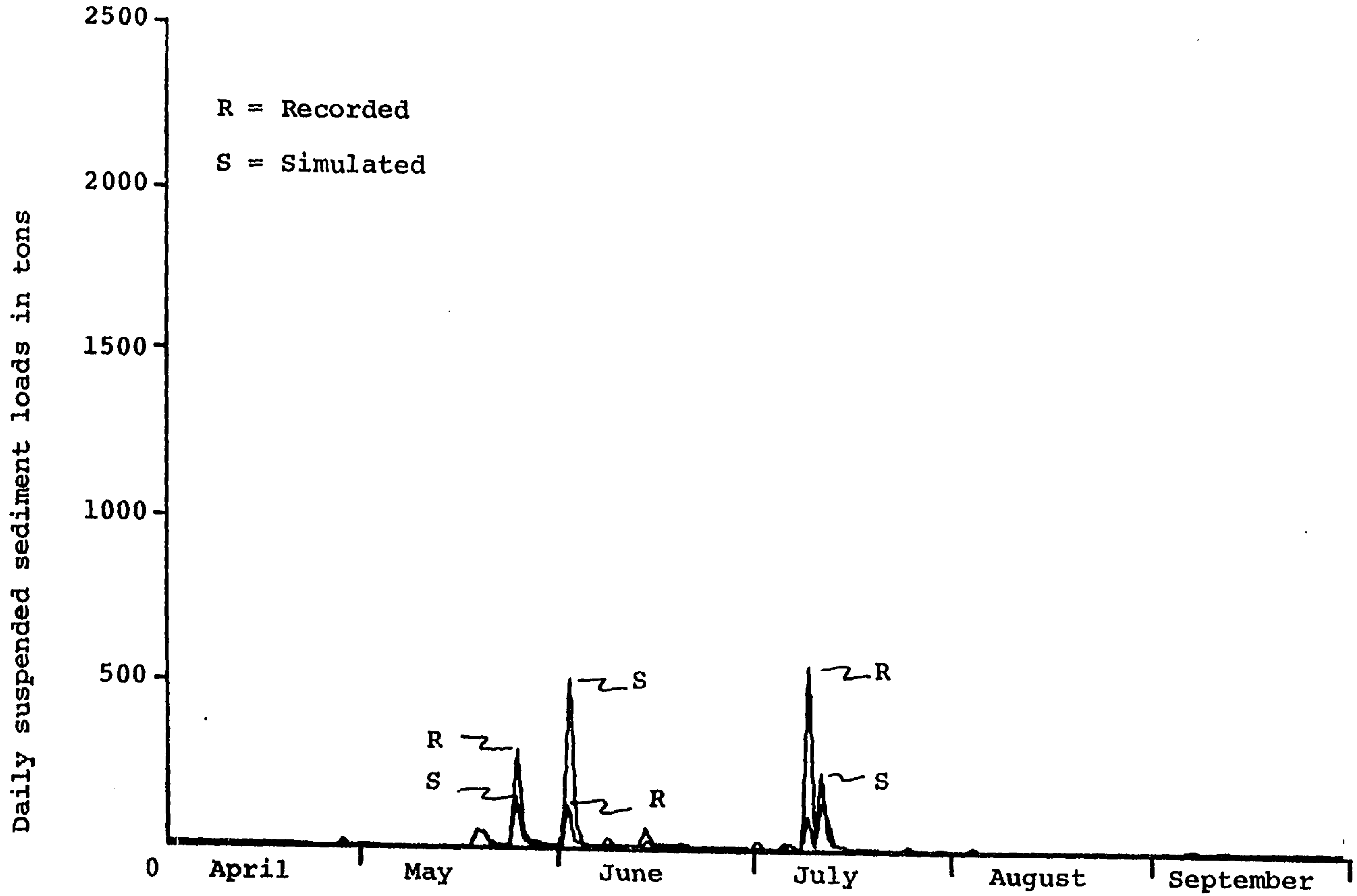

Figure 17 (Continued)

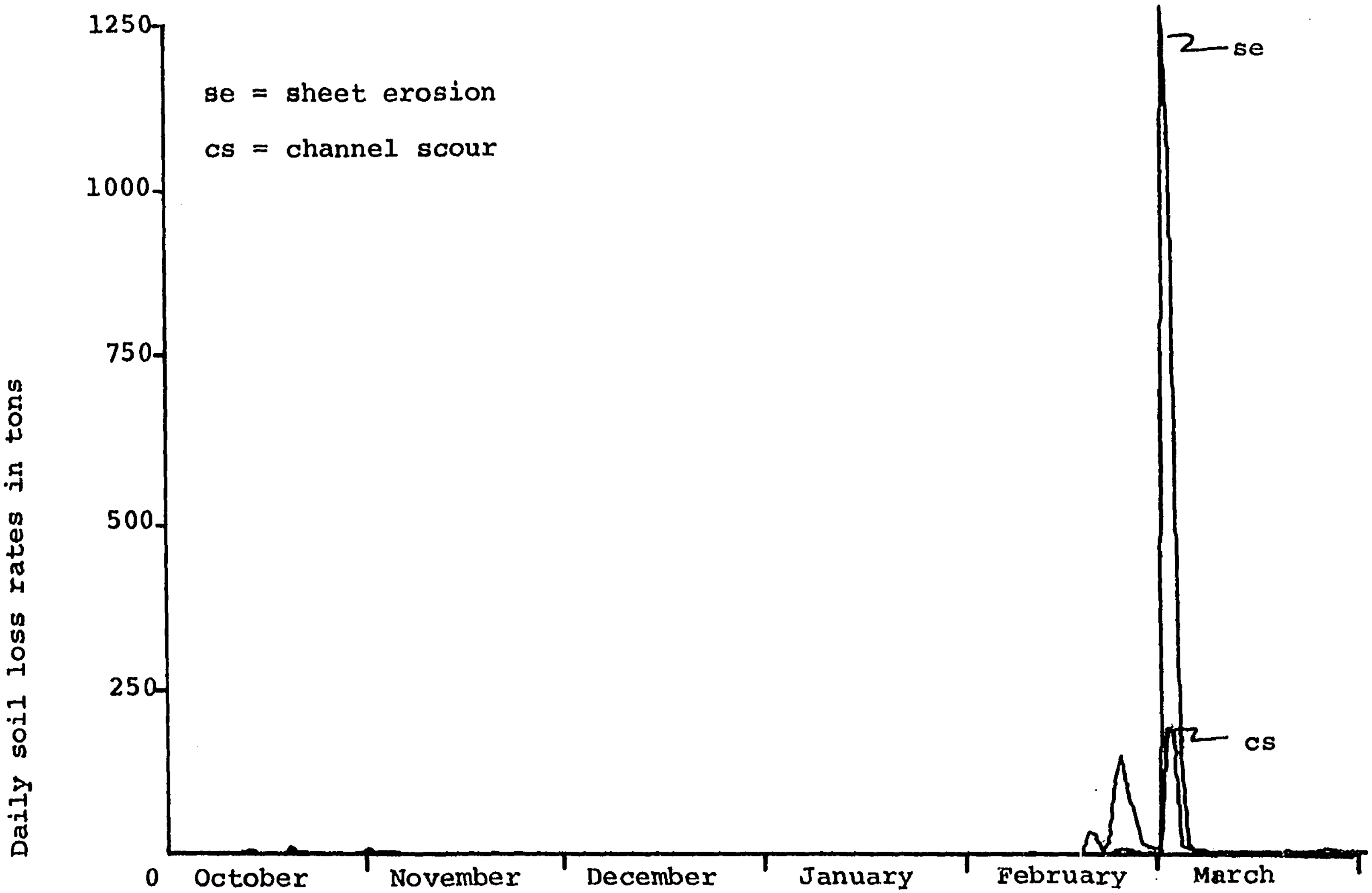

Figure 18. Daily simulated sheet and channel scour erosion rates for Four Mile Creek watershed near Traer, Iowa for the 1970 water year

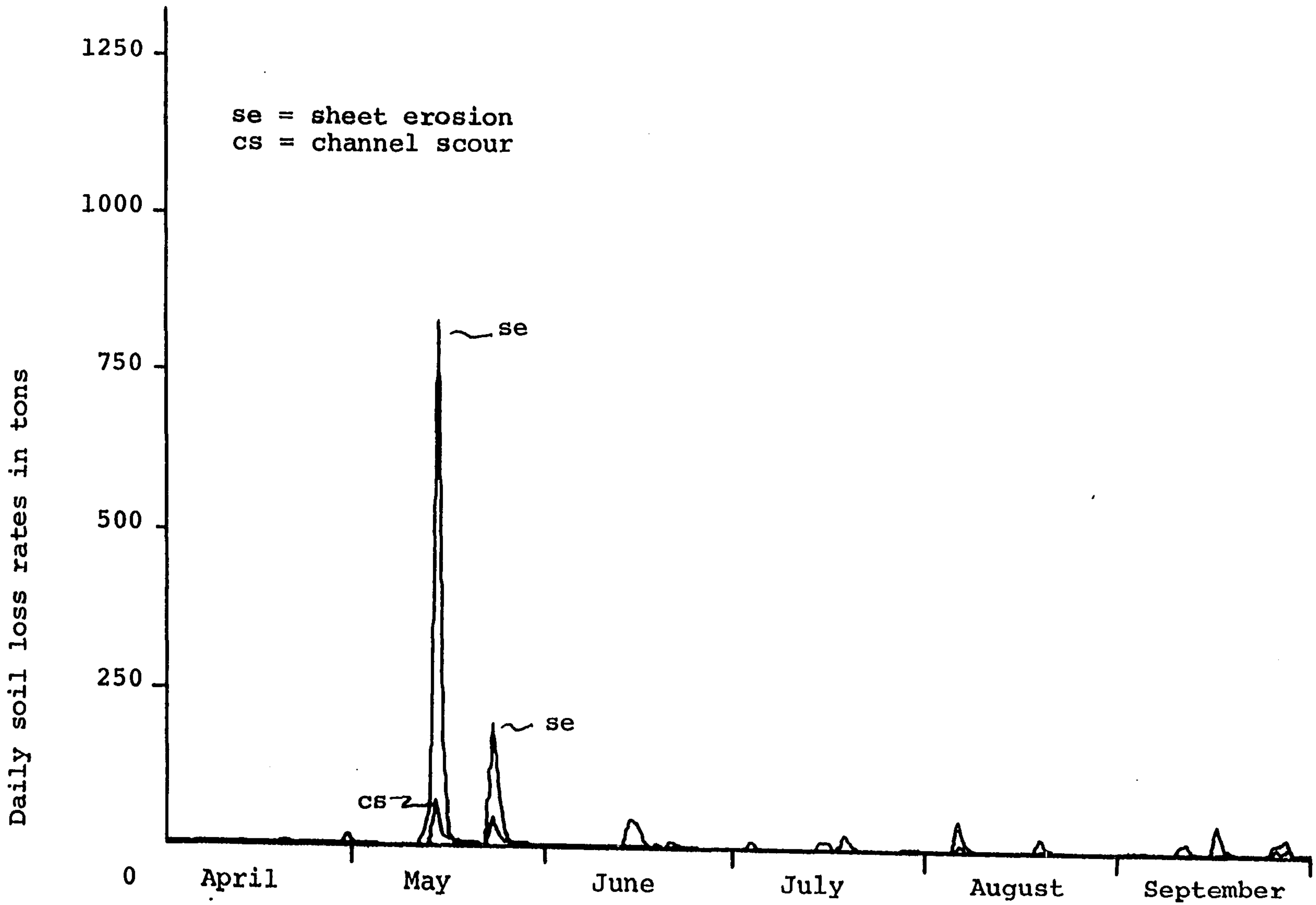

Figure 18 (Continued)

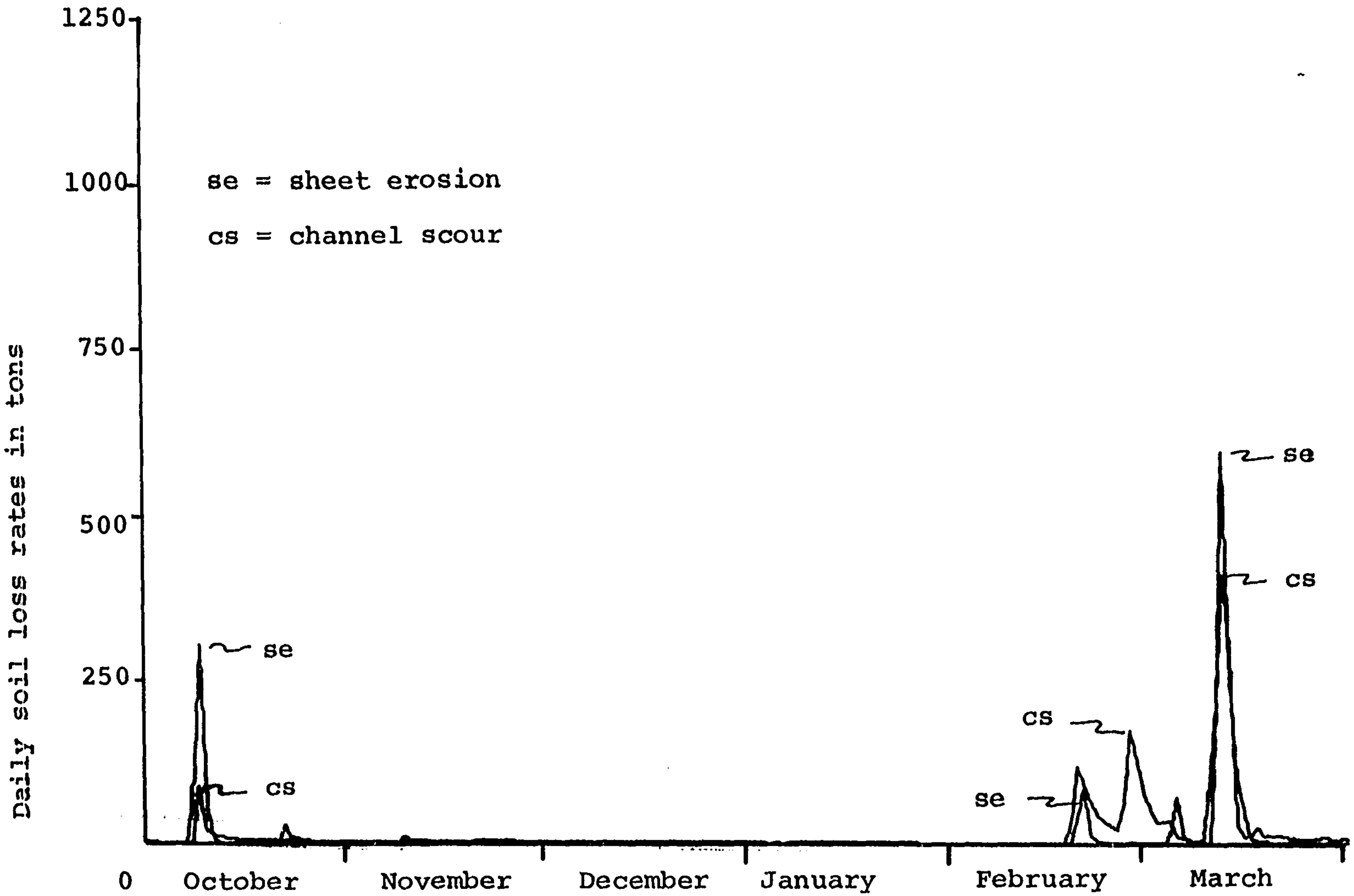

Figure 19. Daily simulated sheet and channel scour erosion rates for Four Mile Creek watershed near Traer, Iowa for the 1971 water year

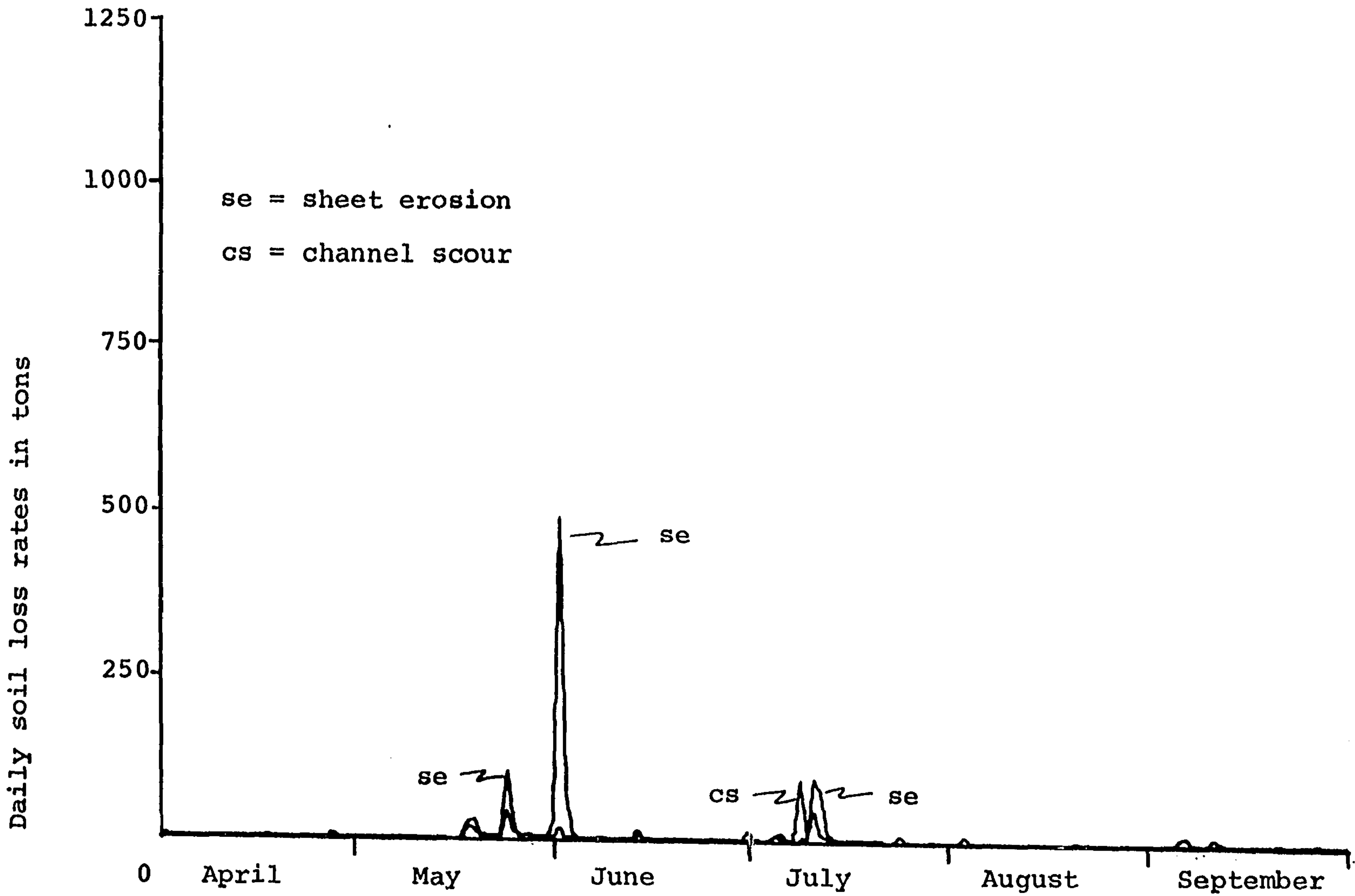

Figure 19 (Continued)

Table 7. Monthly and annual recorded and simulated suspended sediment loads for Four Mile Creek watershed near Traer, Iowa

	Water year 1970 Suspended sediment loads, tons		Water year 1971 Suspended sediment loads, tons	
	Recorded	Simulated	Recorded	Simulated
October	41.07	59.80	624.80	697.20
November	27.29	31.20	147.50	125.30
December	15.31	13.70	95.90	71.20
January	11.01	9.70	56.81	40.90
February	326.50	553.00	997.64	931.10
March	1,816.10	2,976.60	5,478.80	2,764.40
April	30.20	106.10	99.14	108.90
May	1,857.84	1,651.00	542.14	395.30
June	53.14	177.40	401.70	733.60
July	10.03	89.80	925.37	448.70
August	109.07	113.40	10.91	19.90
September	135.23	209.10	4.67	39.70
Total	4,432.61	5,990.80	9,385.38	6,376.20
Correlation Coefficient (Daily)	0.85		0.90	

Table 8. Monthly and annual simulated sheet and channel scour erosion rates for the Four Mile Creek watershed near Traer, Iowa

	Water year 1970 soil loss, tons		Water year 1971 soil loss, tons	
	sheet erosion	channel scour	sheet erosion	channel scour
October	31.5	28.3	470.7	226.5
November	1.2	30.0	15.9	109.4
December	0.0	13.7	0.8	70.4
January	0.8	8.9	0.0	40.9
February	25.0	528.0	139.1	792.0
March	2,505.2	471.4	1,312.2	1,452.2
April	43.4	62.7	28.0	80.9
May	1,408.3	242.7	227.4	167.9
June	126.3	51.1	620.7	112.9
July	80.1	9.7	241.4	207.3
August	88.6	24.8	13.0	6.9
September	166.4	42.7	37.9	1.8
Total	4,476.8	1,514.0	3,107.1	3,269.2

Table 7 shows that most of the annual soil loss occurred during the period from February through May. During these months the soil surface is bare and the soil is usually at or near field moisture capacity. Hence, these are usually the months of high overland flows. From June through October, the influence of vegetation becomes more pronounced. Runoff events are usually of low magnitude as a result of increased rainfall interception and higher evapotranspiration rates. As a result, the soil loss rates during this period are relatively low.

The relative proportion of sheet erosion to the total annual soil loss is highly dependent on the characteristics of the individual runoff events as well as their distribution throughout the water year. During the winter period this proportion will be small if the precipitation is in the form of snow. In such a case detachment by rainfall is zero and the availability of loose soil particles in storage (TSST) is the limiting factor to sediment transportation. Under such a condition, channel scour becomes the relatively more significant source of suspended sediment load. It must be pointed out, however, that if significant precipitation in the form of rain occurs simultaneously with snowmelt, sheet erosion will be the more significant source of suspended sediment load. This was the case during the first week in March of 1970.

During the period of the water year from May through October, most of the suspended sediment load comes from sheet erosion (see Table 8). For this period, the percentages of the total suspended sediment load coming from sheet erosion are 83 and 63 per cent for the 1970 and 1971 water years, respectively. For the period from November through January there is very little runoff due to either rain or snowmelt.

Generally, the sediment simulation results for the test watershed are fair considering the complexity of the soil erosion process. In comparing the simulated to the recorded sediment loads, it is to be noted that some of the apparent discrepancies may be due to errors in the recorded data themselves. As pointed out by Negev (1967), these errors may be due to (1) an insufficient number of sampling verticals to define the true average concentration in a cross section and (2) insufficient number of measurements to define the true time average concentration. Benedict *et al*. (1955) found that errors due to the first and second causes could be as high as 25 and 85.3 per cent, respectively.

The simulated loads for the 1971 water year are lower than the recorded loads. Most of this discrepancy occurred during the three-day period from March 12 through 14 when approximately one-half of the total recorded annual suspended sediment load was observed. This points toward some inherent errors in the erosion model in itself. Since no significant rainfall was recorded during this three-day period, the most likely source of error is the channel scouring component of the erosion model. It is to be noted that the channel scouring component of the erosion model uses the average daily recorded streamflows instead of hourly or quarter-hourly streamflows. Since the expression relating channel scour to streamflow is of the exponential form, errors due to such time averaging are to be expected.

In reviewing the errors detected in the simulated suspended sediment load, the errors associated with recorded streamflows must not be overlooked. It is to be noted that the quality of the runoff records during the winter months of January, February, and March are classified as poor due to the effect of ice on the streamflows. Since the recorded suspended sediment load is computed by multiplying the mean water discharge during a time interval by the concentration of the suspended material measured during that time, the errors in the streamflow estimates will be transferred to the suspended sediment load data.

The discrepancies between the recorded and simulated sediment loads may also be due to the fact that the hourly rainfall amounts were taken from a raingage located outside the catchment area. It is apparent from Equation (4-4) that the amounts of soil detached by raindrops is highly dependent on the assumed hourly rainfalls. In addition, the hourly or quarter-hourly overland flows as computed by the watershed model are dependent on the assumed hourly rainfalls.

Application of the Model to the Skunk River Watershed near Ames, Iowa

As the study of the Four Mile Creek watershed neared completion, the sedimentation hazards on the Skunk River above Ames, Iowa needed to be evaluated. This is in connection with the environmental resources study of the proposed Ames reservoir. This study is currently being conducted jointly by the Iowa State University and the State University of Iowa. Exploratory simulation studies on the Skunk River are currently being conducted using the proposed sheet erosion model.

A map of the watershed showing the locations of the streamflow gaging stations below Ames and upstream of Ames and the raingages is shown on Figure 20. The dam site for the proposed reservoir is adjacent to the upstream gaging station which has a drainage area of 315 square miles. Since there are no suspended sediment load records available on the upstream gaging station, the larger watershed represented by the gaging station below Ames is the one being used in the simulation attempts. This watershed has a drainage area of 556 square miles.

The preliminary simulation results were inconclusive. A problem was encountered in the streamflow simulation using the watershed model. The watershed is too large and the raingages are too few to obtain representative hourly rain-

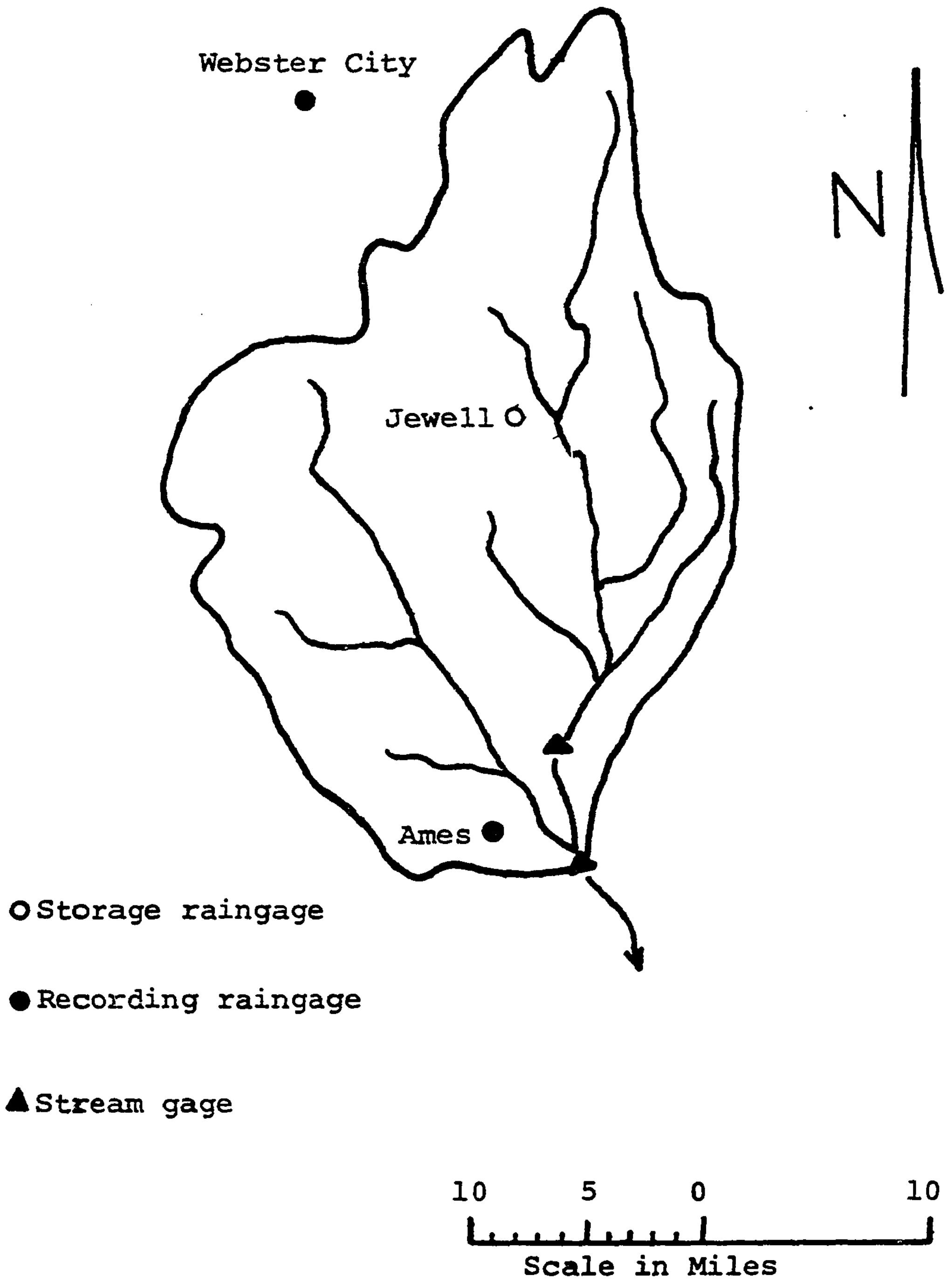

Figure 20. Skunk River watershed near Ames, Iowa

falls for the entire watershed. Large discrepancies in the measured rainfalls have been observed between the two recording raingages at Ames and Webster City. The storage raingage at Jewell also showed greater recorded rainfall discrepancies when compared with that at Ames which is less than 30 miles away. For example, during the month of June, 1968, the Ames station recorded 9.09 inches of rain while the Jewell station recorded only 0.13 inches.

Another difficulty encountered in the simulation attempt was evaluating the quality of the suspended sediment load records. Suspended sediment load measurements are available for the water years from 1968 through 1971. These measurements were, however, usually taken at weekly or bi-weekly intervals. The daily sediment loads for the rest of the week have to be roughly approximated.

The existence of many surface depressions or potholes on the upper sections of the watershed poses some difficulties in the simulation attempts. The presence of these potholes as well as the size of the watershed point toward the need for watershed segmentation using perhaps a different watershed model for each segment. However, even if time and effort are available for such a segmentation study, the scarcity of raingages within the watershed will still prove to be a serious drawback in simulating the streamflows and sediment loads from the watershed.

Although the Four Mile Creek watershed and the Skunk River watershed represented by the streamgage below Ames are only about 60 miles apart, the differences in size, topographic features, and in geology between the two watersheds limit the application of the simulation results from the former to the latter watershed. Most of the Skunk River watershed parameters required by sheet erosion as well as the watershed model would need to be evaluated by fitting or trial and error.

CHAPTER VI. SUMMARY AND CONCLUSIONS

A sheet erosion model on a digital computer was developed to simulate suspended sediment loads on small agricultural watersheds. The model is used in conjunction with a modified version of the Stanford Watershed Model. To evaluate its feasibility, the erosion model was tested on the Four Mile Creek watershed near Traer, Iowa. Four Mile Creek is an agricultural watershed having a drainage area of 19.51 square miles.

The first step in using the sheet erosion model is the calibration of the watershed model. The watershed model used was the Kentucky Watershed Model (KWM) which is a modified version of the Stanford Watershed Model. The essentials of the KWM were presented in Chapter III. The watershed model was calibrated using the 1969 and 1970 water years. The calibrated watershed model was then tested on the 1971 water year and the simulation results were summarized in Chapter V.

The essentials of the proposed sheet erosion model were presented in Chapter IV. The model was calibrated for the Four Mile Creek watershed using the 1970 water year. It was then tested using 1971 as the test water year. The suspended sediment load simulation results were reported in Chapter V. This chapter presents the conclusions derived from the exploratory simulation results and analyzes the errors involved in them.

On the basis of the results from this study, the following conclusions were made:

1. The erosion model will reproduce, within a 35 per cent error, annual, monthly, and daily suspended sediment loads from the test watershed if accurate overland flow values can be synthesized by the accompanying watershed model.

2. With some modifications and adaptations to the existing watershed conditions, the Kentucky Watershed Model will simulate annual, monthly, and daily streamflows from the test watershed within a 30 per cent error.

3. The occurrence of snowmelt is a serious problem with the Kentucky Watershed Model. The model has to be modified to include a working snowmelt subroutine if consistent and accurate streamflow simulation results are to be obtained with its use in places where snowmelt runoff is significant. The snowmelt subroutine listed in Appendix A has been found to yield inconsistent results from one water year to another. For this same reason, the self-calibrating version of the KWM was found to be unapplicable to the test watershed.

3. The sheet erosion model cannot be applied to large watersheds. Preliminary studies with the 556 square mile South Skunk River north of Ames, Iowa indicate that with a large watershed, it is not possible to obtain representative

hourly rainfall and, hence, overland flow values for the watershed. Since most of the components of both the watershed and erosion models are based on nonlinear relationships, averaging rainfall and overland flow values presents a very serious limitation. This points toward the need for watershed segmentation which is not provided for in the Kentucky Watershed Model.

4. A serious drawback in using the Kentucky Watershed Model is the great amount of time required to become acquainted with it in order to interpret its outputs. Understanding the model is essential to the proper adjustment of the watershed parameters.

5. The most serious limiting factor to further development and evaluation of the proposed erosion model lies on the accompanying watershed model. The watershed model size dictates that a high speed and large storage digital computer be available. In order to become familiarized with the watershed model and determine the best basin parameters much computer time is required. Experience on the Four Mile Creek watershed indicates that as many as 40 computer runs may be needed to calibrate the model. The computer execution time needed to simulate one water year of data is about 35 seconds. This is equivalent to about five dollars at the current commercial rate at the Iowa State University Computation Center. Thus calibrating the watershed model for several water years

for each of several test watersheds can be costly.

6. The calibration of the sheet erosion model after the watershed model may require 20 computer runs or more. Because much computer time is required no serious attempts to conduct sensitivity studies on the sheet erosion parameters have been made.

7. As a final conclusion, it is felt that from the basis of the results presented in Chapter V that the sheet erosion model (when used with the Stanford Watershed Model or its kind), appears to form a sound and workable foundation for erosion simulation works.

The errors in the simulation studies may be caused by the following:

1. Deficiencies in the sheet erosion model. Obviously, some of the errors in the simulation attempts result from the deficiencies in the sheet erosion model itself. One of the probable deficiencies in the model is the assumption that the channel bank caving and bed scouring component of the model is a simple power function of the mean daily recorded flows. Since for a given average daily streamflow various types of daily runoff hydrographs are possible, errors due to such time averaging are to be expected. Another apparent deficiency in the model is its lack of a gully erosion component. Gully erosion is a complex process and no satisfactory equations describing this process are available.

Other deficiencies that can be attributed to the model include the lack of components describing sediments deposition along the flood plain and the lack of sufficient parameters to define the seasonal effects on some of the sheet erosion parameters. Also, the expressions for rainfall detachment and transport as well as overland flow scouring used in the model were approximations that need further improvements. The correction of some or all of the above deficiencies would, of course, require more time and data than are available for this study.

2. Errors in the recorded daily streamflows. These errors may result from insufficient number of samples to define the average streamflows, changes in the channel geometry near the gaging station as a result of channel aggradation and degradation, and ice effect on the streamflow measurements during the winter period.

3. Errors in the recorded suspended sediment loads. As mentioned before, these errors may be due to the inadequacy of the sediment sampling procedure to define the true average sediment concentration in the stream at all times. They may also be due to the errors in the streamflow data which are used in estimating the average daily suspended sediment loads.

4. Errors due to nonrepresentative hourly rainfalls and overland flows. The hourly rainfalls are the most

critical inputs to the sheet erosion model. Not only are they used to estimate the rainfall detachment and transport functions in the erosion model but they are also used by the watershed model to synthesize the overland flow values. The hourly rainfall values used in the Four Mile Creek simulation study were taken from a recording raingage located outside and about 7.5 miles from the center of the watershed. A study of Ruhe and Vreeken (1969) has shown that these hourly rainfalls do not represent those within the watershed at all times.

CHAPTER VII. SUGGESTIONS FOR FURTHER RESEARCH

Due to the exploratory nature of this study, numerous possible extensions of it are evident. Some possible improvements in the watershed model were mentioned in Chapter VI in presenting the conclusions from this study. Some possible improvements in the sheet erosion model were also mentioned in Chapter VI in discussing the deficiencies of the model. Other possible extensions include the following.

1. There is a need for a comprehensive mathematical submodel of the rainfall detachment process. Such a model may be based on a much more detailed form of Equation (4-5). It should include the influence of rainfall and soil characteristics, particularly as they vary with time.

2. The expressions for rainfall detachment and transport functions of the sheet erosion model were approximations based on a detailed review of currently available information. Improved relationships based on further experimental research are needed.

3. There is a need to investigate the contribution of raindrop and prerill flow detachment as compared to the contribution of rill flow detachment in making up the total sheet erosion losses. The mechanics of sediment delivery to rills by rainfall and prerill overland flow is an important phase of the sheet erosion process which has not been fully

described. Consequently, there is a question as to the conditions under which detachment is limiting on these unrilled sections versus those conditions where transport is limiting.

4. The application of the sheet erosion model to larger watersheds should be developed. A small watershed, for convenience, may be defined as one having a drainage area of less than 100 square miles. Large watersheds should be segmented and the outputs of the individual segments should then be combined.

5. The erosion model should be tested in other regions to further evaluate its feasibility. Tests on watersheds with two or more distinct rainfall seasons and on those undergoing some urbanization may disclose the need for further model modifications.

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APPENDIX A. LISTING OF WATERSHED AND SHEET EROSION MODELS

```
C   SHEET  EROSICN MODEL   WILLIE  DAVID   FEBRUARY, 1972              MAIN0001
C   SUPERIMPOSED ON THE KENTUCKY WATERSHED MODEL OF JUNE 6, 1970       MAIN0002
C    WHICH IS BASED ON THE STANFORD WATERSHED MODELS III & IV          MAIN0003
C                                                                      MAIN0004
      DIMENSICN BTRI(99), CONOPT(20), CRFMI(22), CTRI(99), DDIW(366),  MAIN0005
     1  DMNT(366), DMXT(366), DPSE(366), DRGPM(366), DRHP(366,24),     MAIN0006
     2  DRSGP(366), DPET(366), DRSF(366), DSSF(366), EDLZS(366),       MAIN0007
     3  EMBFNX(12), EMGWS(12), EMIFS(12), EMLZS(12), EMSIAM(12),       MAIN0008
     4  EMUZC(12), EMUZS(12), EPCM(12), FIRR(15), MEDCY(12), MEDWY(12) MAIN0009
      DIMENSICN  SATRI(99), SERA(22), SERR(22), SESF(22), SQER(22),    MAIN0010
     6  THSF(24), TITLE(20), TMBF(12), TMFSIL(12), TMIF(12), TMNET(12), MAIN0011
     7  TMOF(12), TMPET(12), TMPREC(12), TMRPM(12), TMRTF(12), TMSE(12),MAIN0012
     8  TMSNE(12), TMSTF(12), TMSTFI(12), T200FH(21), T20PRH(21),      MAIN0013
     9  UHFA(99), YTITLE(20),RICY(366),RWPD(12)                        MAIN0014
      DIMENSICN DRSL(366),DSSL(366),USFA(99),TSSF(24),SCOUR(366),      MAIN0015
     1 DSSE(366)                                                       MAIN0016
      LOGICAL  LSHFT                                                   MAIN0017
      INTEGER  COSDR,CN,CONOPT,DATE,DAY,DPY,EHSGD,HOUR,HRF,HRL,PDAY,   MAIN0018
     1  PRD,RHPD,RHPH,RSBD,SGMD,SGRT,SGRT2,YEAR,YR1,YR2                MAIN0019
      REAL  IFPRC,IFRC,IFRL,IFS,LZC,LZRX,LZS,LZSR,MHSM,MNRD,MRNSM,NHPT MAIN0020
      CATA  MEDCY/  0,        31,59,90,120,151,181,212,243,273,304,334/ MAIN0021
      DATA  MEDWY/304,334,365,31,59,90,120,151,181,212,243,273       / MAIN0022
      NYSD = 0                                                         MAIN0023
  100 CCNTINUE                                                         MAIN0024
      READ(5,70)(CONCPT(I),I=1,20)                                     MAIN0025
   70 FORMAT(20I3)                                                     MAIN0026
      DO 102 KIA = 1,99                                                MAIN0027
      SATRI(KIA) = 0.0                                                 MAIN0028
      CTRI(KIA) = 0.0                                                  MAIN0029
      BTRI(KIA) = 0.0                                                  MAIN0030
      USFA(KIA) = 0.0                                                  MAIN0031
  102 UHFA(KIA) = 0.0                                                  MAIN0032
      READ(5,95) NYSQ                                                  MAIN0033
```

```
 95 FORMAT(I2)                                                        MAIN0034
    READ(5,71) NCTRI                                                  MAIN0035
 71 FORMAT(I3)                                                        MAIN0036
    READ(5,72)(CTRI(KRD),KRD=1,NCTRI)                                 MAIN0037
 72 FORMAT(11F7.4)                                                    MAIN0038
    IF(CONOPT(7) .NE. 1) GO TO 110                                    MAIN0039
    READ(5,73)(FIRR(I),I=1,15)                                        MAIN0040
 73 FORMAT(15F5.2)                                                    MAIN0041
    DO 106 KRD = 274,360,10                                           MAIN0042
106 READ(5,75)DPSE(KRD)                                               MAIN0043
 75 FORMAT(F6.3)                                                      MAIN0044
    DO 107 KRD = 1,273,10                                             MAIN0045
107 READ(5,75)DPSE(KRD)                                               MAIN0046
    DO 109 IDAY2 = 1, 9                                               MAIN0047
    DO 108 IDAY1 = 274,360,10                                         MAIN0048
    DAY = IDAY1 + IDAY2                                               MAIN0049
108 DPSE(DAY) = DPSE(IDAY1)                                           MAIN0050
    DO 109 IDAY1 = 1,273,10                                           MAIN0051
    CAY = ICAY1 + IDAY2                                               MAIN0052
    IF(DAY .GT. 273) GO TO 109                                        MAIN0053
    DPSE(CAY) = DPSE(IDAY1)                                           MAIN0054
109 CONTINUE                                                          MAIN0055
    DPSE(366) = DPSE(59)                                              MAIN0056
    DPSE(365) = DPSE(363)                                             MAIN0057
    DPSE(364) = DPSE(363)                                             MAIN0058
    READ(5,77) BDDFSM,SPBFLW,SPTWCC,SPM,ELDIF,XDNFS,FFOR,FFSI,MRNSM,  MAIN0059
   1  DSMGH,PXCSA                                                     MAIN0060
 77 FCRMAT(11F7.4)                                                    MAIN0061
110 READ(5,78) RMPF,RGPMB,AREA,FIMP,FWTR                              MAIN0062
 78 FORMAT(2F6.2,F7.2,2F7.4)                                          MAIN0063
    READ(5,79) VINTMR,BUZC,SUZC,LZC,ETLF,SUBWF,GWETF,SIAC,BMTR,BIVF   MAIN0064
 79 FORMAT(10F7.3)                                                    MAIN0065
    READ(5,80) OFSL,CHCAP,OFSS,OFMN,OFMNIS,IFRC,CSRX,FSRX,EXQPV,BFNLR,MAIN0066
   1  BFRC                                                            MAIN0067
 80 FCRMAT(2F7.1,9F7.4)                                               MAIN0068
    BFHRC = BFRC**(1.0/24.0)                                          MAIN0069
```

```
      BFRL = -ALOG(BFHRC)
      BFNRL = 0.0
      IF(BFNLR .LT. 0.00001 .OR. BFNLR .GT. 0.9999) GO TO 111
      BFNHR = BFNLR**(1.0/24.0)
      BFNRL = -ALOG(BFNHR)
  111 IFPRC = IFRC**(1.0/96.0)
      IFRL = -ALOG(IFPRC)
      READ(5,81) GWS,UZS,LZS,BFNX,IFS,GFIE,NDTUZ
   81 FORMAT(6F7.4,I3)
      IF(CONOPT(15).NE.1) GO TO 444
      READ(5,303) ALP1,ALP2,ALP3,ALP4,ALP5,KDAY1,KDAY2
  303 FORMAT(5F10.4,2I4)
      READ(5,305) BETA1,BETA2,BETA3,BETA4,BETA5,BETA6
  305 FORMAT(6F12.4)
      READ(5,307) ISST1,ISST2,AISS
  307 FORMAT(2I4,F8.1)
  444 CONTINUE
      LSHFT = .FALSE.
      IF(CONOPT(13) .NE. 1) GO TO 113
      NBTRI = NCTRI
      FNTRI = NCTRI
      MXTRI = (10.0**EXQPV)*FNTRI + 0.5
      IF(MXTRI .GE. 98) WRITE(6,1)
    1 FORMAT(29HWARNING: EXQPV ARRAY OVER RUN)
      NCSTRI = 99
      DO 112 KIA = 1, NBTRI
  112 BTRI(KIA) = CTRI(KIA)
      TFCFS = 1.0
      CALL RTVARY (CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCSTRI,EXQPV,LSHFT,
     1  TFCFS)
  113 EPAET = 0.0
      FPER = 1.0 - FIMP - FWTR
      IF(FPER .GT. 0.01) GO TO 114
      TPLR = 100.0
      FPER = 0.01
      GO TO 115
```

```
114 TPLR = (1.0 - FWTR)/FPER                                      MAIN0106
115 VINTCR = 0.25*VINTMR                                          MAIN0107
    HSE = 0.0                                                     MAIN0108
    NRTRI = 0                                                     MAIN0109
    PEAI = 0.0                                                    MAIN0110
    SPIF = 0.0                                                    MAIN0111
    CBF = GWS*BFRL*(1.0 + BFNRL*BFNX)                             MAIN0112
    SPDR = 0.0                                                    MAIN0113
    OFUS = 0.0                                                    MAIN0114
    OFUSIS = 0.0                                                  MAIN0115
    OFR = 0.0                                                     MAIN0116
    OFRIS = 0.0                                                   MAIN0117
    PEIS = 0.0                                                    MAIN0118
    RHFO = 0.0                                                    MAIN0119
    RSDFO = 0.0                                                   MAIN0120
    URHF = 0.0                                                    MAIN0121
    URSF = 0.0                                                    MAIN0122
    TSST = 0.0                                                    MAIN0123
    AMIF = 0.0                                                    MAIN0124
    AMNET = 0.0                                                   MAIN0125
    AMPET = 0.0                                                   MAIN0126
    AMSNE = 0.0                                                   MAIN0127
    AMFSIL = 0.0                                                  MAIN0128
    SASFX = 0.0                                                   MAIN0129
    SARAX = 0.0                                                   MAIN0130
    SRX = CSRX                                                    MAIN0131
    VWIN = 26.8888*AREA                                           MAIN0132
    WCFS = 24.0*VWIN                                              MAIN0133
    RHFMC = 0.025/WCFS                                            MAIN0134
    TFCFS = CBF*WCFS                                              MAIN0135
    SSRT = SQRT(OFSS)                                             MAIN0136
    OFRF = 1020.0*SSRT/(OFMN*OFSL)                                MAIN0137
    OFRFIS = 1020.0*SSRT/(OFMNIS*OFSL)                            MAIN0138
    EQDF = 0.00982*((OFMN*OFSL/SSRT)**0.6)                        MAIN0139
    EQDFIS = 0.00982*((OFMNIS*OFSL/SSRT)**0.6)                    MAIN0140
    SOFRF = OFRF                                                  MAIN0141
```

```
      SOFRFI = OFRFIS                                                   MAIN0142
      SDEPTH = 0.0                                                      MAIN0143
      ASM = 0.0                                                         MAIN0144
      IF(CONOPT(7) .EQ. 0) GO TO 116                                    MAIN0145
      WT4AM = 60.0                                                      MAIN0146
      WT4PM = 60.0                                                      MAIN0147
      SAX = 15.0                                                        MAIN0148
      TANSM = 0.0                                                       MAIN0149
      SPTW = 0.0                                                        MAIN0150
      STMD = C.7                                                        MAIN0151
      SFMD = C.7                                                        MAIN0152
      ASMRG = 0.0                                                       MAIN0153
  116 READ(5,2) TITLE                                                   MAIN0154
    2 FCRMAT(20A4)                                                      MAIN0155
C  BEGIN NEW YEAR                                                       MAIN0156
  117 BYLZS = LZS                                                       MAIN0157
      BYUZS = UZS                                                       MAIN0158
      NYSD = NYSD + 1                                                   MAIN0159
      BYGWS = GWS                                                       MAIN0160
      BYIFS = IFS                                                       MAIN0161
      DO 118 KIA = 1,22                                                 MAIN0162
      CRFMI(KIA) = 0.0                                                  MAIN0163
      SESF(KIA) = 0.0                                                   MAIN0164
      SERR(KIA) = 0.0                                                   MAIN0165
      SERA(KIA) = 0.0                                                   MAIN0166
  118 SQER(KIA) = 0.0                                                   MAIN0167
      RGPM = RGPMB                                                      MAIN0168
      DO 119 KIA = 1,21                                                 MAIN0169
      T20FH(KIA) = 0.0                                                  MAIN0170
  119 T20PRH(KIA) = 0.0                                                 MAIN0171
      DO 120 KIA = 1,12                                                 MAIN0172
  120 EPCM(KIA) = 1.0                                                   MAIN0173
      RDPT = 0.0                                                        MAIN0174
      PDAY = 274                                                        MAIN0175
      READ(5,82) YR1,YR2                                                MAIN0176
   82 FORMAT(2I3)                                                       MAIN0177
```

```
      READ (5,2)YTITLE
      DPY = 365
      IF(MOD(YR2,4) .EQ. 0) DPY = 366
      IF(CONOPT(1).EQ.1) READ(5,67) CDSDR,NDSDR
   67 FORMAT(2I4)
      NDSDP = 0
      MEDWY(5) = 59
      IF(DPY .EQ. 366) MEDWY(5) = 366
C  READ EVAPORATION CATA
      IF(CONOPT( 3) .NE. 1) GO TO 125
      DO 121 KRD = 274,360,10
  121 READ(5,83) DPET(KRD)
   83 FORMAT(F5.3)
      DO 122 KRD = 1,273,10
  122 READ(5,83) DPET(KRD)
      DO 124 ICAY2 = 1,9
      DO 123 IDAY1 = 274,360,10
      DAY = ICAY1 + IDAY2
  123 DPET(DAY) = DPET(IDAY1)
      DO 124 IDAY1 = 1,273,10
      DAY = ICAY1 + IDAY2
      IF(DAY .GT. 273) GO TO 124
      DPET(DAY) = DPET(IDAY1)
  124 CONTINUE
      DPET(366) = DPET(59)
      DPET(365) = DPET(363)
      DPET(364) = DPET(363)
      GO TO 127
  125 READ(5,84) NDIM,NDFM
   84 FORMAT(2I4)
      NDIM2 = NDIM + 1
      NDFM1 = NDFM - 1
      DO 60 ICP = NDIM2,DPY
   60 DPET(ICP) = 0.03
      DO 61 IP = 1,60
   61 DPET(IP) = 0.03
```

```
      DO 62 IK = 61,NDFM1                                              MAIN0214
   62 DPET(IK) = 0.15                                                  MAIN0215
      READ(5,85)(DPET(DAY),DAY =NDFM,NDIM)                             MAIN0216
   85 FCRMAT(15F5.2)                                                   MAIN0217
  127 IF(EPAET .NE. 0.0) GO TO 381                                     MAIN0218
      DO 129 CAY = 1,DPY                                               MAIN0219
  129 EPAET = EPAET + 0.60*DPET(DAY)                                   MAIN0220
  131 AETX = 24.0*EPAET/365.0                                          MAIN0221
      AEX96 = 1.2*AETX                                                 MAIN0222
      AEX90 = 0.3*AETX                                                 MAIN0223
      SIAM = 1.2**SIAC                                                 MAIN0224
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)                        MAIN0225
      IF(UZC .LT. 0.25) UZC = 0.25                                     MAIN0226
  381 SGRT = C                                                         MAIN0227
      DO 132 CAY = 1,366                                               MAIN0228
      DDIW(DAY) = 0.0                                                  MAIN0229
      DRSF(DAY) = 0.0                                                  MAIN0230
      DRSL(DAY) = 0.0                                                  MAIN0231
      DRGPM(CAY) = RGPMB                                               MAIN0232
      DRSGP(DAY) = 0.0                                                 MAIN0233
      DO 132 HOUR = 1,24                                               MAIN0234
  132 DRHP(DAY,HOUR) = 0.0                                             MAIN0235
  133 IF(CONOPT(9) .NE. 1) GO TO 138                                   MAIN0236
      DRSF(366) = 0.0                                                  MAIN0237
      READ(5,86)(DRSF(CAY),DAY = 1,DPY)                                MAIN0238
   86 FORMAT(12F6.1)                                                   MAIN0239
  138 IF(CONOPT(16).NE.1) GO TO 135                                    MAIN0240
      DRSL(366) = 0.0                                                  MAIN0241
      READ(5,300)(DRSL(DAY), DAY = 1,DPY)                              MAIN0242
  300 FORMAT(8F10.2)                                                   MAIN0243
  135 IF(CONOPT(11) .NE. 1) GO TO 137                                  MAIN0244
      DDIW(366) = 0.0                                                  MAIN0245
  136 REAC(5,86)(DDIW(DAY),DAY = 1,DPY)                                MAIN0246
  137 IF(CONOPT(7) .EQ. 0) GO TO 139                                   MAIN0247
      DO 65 I = 121,304                                                MAIN0248
   65 RICY(I) = 48.0                                                   MAIN0249
```

```
      READ(5,66)(RICY(CAY),DAY = 1,120)                                 MAIN0250
      READ(5,66)(RICY(DAY),DAY = 305,366)                               MAIN0251
   66 FORMAT(13F6.1)                                                    MAIN0252
      DO 68 IN = 121,304                                                MAIN0253
      DMXT(IN) = 80.0                                                   MAIN0254
   68 DMNT(IN) = 60.0                                                   MAIN0255
      READ(5,69)(DMXT(CAY),DAY = 1,120)                                 MAIN0256
      READ(5,69)(DMXT(DAY),DAY = 305,366)                               MAIN0257
      READ(5,69)(DMNT(CAY),DAY = 1,120)                                 MAIN0258
      READ(5,69)(DMNT(DAY),DAY = 305,366)                               MAIN0259
   69 FORMAT(15F5.1)                                                    MAIN0260
  139 READ(5,87) NSGRD                                                  MAIN0261
   87 FORMAT(I3)                                                        MAIN0262
      IF(NSGRC .EQ. 0) GO TO 141                                        MAIN0263
      READ(5,88) WSG,SGRT                                               MAIN0264
   88 FORMAT(F7.4,I3)                                                   MAIN0265
      IF(CCNOPT(8).EQ.1) READ(5,89) WSG2,SGRT2,SGMD                     MAIN0266
   89 FORMAT(F7.4,2I3)                                                  MAIN0267
      DO 140 KRD = 1,NSGRD                                              MAIN0268
  140 READ(5,90) ISGRD,DRSGP(ISGRD)                                     MAIN0269
   90 FORMAT(I3,F7.4)                                                   MAIN0270
C  READ RECORDING RAIN GAGE HOURLY TOTALS                               MAIN0271
  141 READ(5,91) YEAR,MONTH,DATE,CN,(RWPD(I),I = 1,12)                  MAIN0272
   91 FORMAT(3I4,I3,12F5.2)                                             MAIN0273
C  PUNCH NO NUMBER AFTER CN ON YEAR .EQ. 98 CARD                        MAIN0274
      IF(YEAR .GE. 98) GO TO 144                                        MAIN0275
      HRF = 12*(CN - 1) + 1                                             MAIN0276
      HRL = 12*(CN - 1) + 12                                            MAIN0277
      LSD = HRF - 1                                                     MAIN0278
      DAY = MEDCY(MONTH) + DATE                                         MAIN0279
      DO 142 HOUR = HRF, HRL                                            MAIN0280
  142 DRHP(CAY,HOUR) = RWPD(HOUR - LSD)                                 MAIN0281
      IF(DPY .NE. 366 .OR. MONTH .NE. 2 .OR. DATE .NE. 29) GO TO 141    MAIN0282
      DO 143 HOUR = HRF, HRL                                            MAIN0283
      DRHP(366,HOUR) = DRHP(60,HOUR)                                    MAIN0284
  143 DRHP(60,HOUR) = 0.0                                               MAIN0285
```

```
      GO TO 141
C  CALCULATE PRECIPITATION WEIGHTING FACTORS
  144 DAY = 274
      IF(NSGRD .EQ. 0) GO TO 151
      PDAY = 274
      RDPT = C.0
  145 EHSGD = SGRT
      IF(SGRT .EQ. 0) EHSGD = 24
      EHSGDF = EHSGD
  146 CONTINUE
      DO 150 HOUR = 1,24
      RDPT = RDPT + DRHP(DAY,HOUR)
      IF(HOUR .NE. EHSGD) GO TO 150
      IF(RDPT .LE. 0.0) GO TO 147
      IF(SGRT .EQ. 0) PDAY = DAY
      DRGPM (PDAY) = (DRSGP(DAY)*WSG + RDPT*(1.0 - WSG))/RDPT
      IF(CONOPT(3) .NE. 0) DPET(PDAY) = 0.5*DPET(PDAY)
      IF(SGRT .NE. 0) PDAY = DAY
      RDPT = C.0
      GO TO 150
  147 IF(DRSGP(DAY) .LE. 0.0) GO TO 149
      DO 148 KHOUR = 1,EHSGD
  148 DRHP(DAY,KHOUR) = (WSG*DRSGP(DAY))/EHSGDF
  149 IF(SGRT .NE. 0) PDAY = DAY
  150 CONTINUE
      CALL DAYNXT(DAY,DPY)
      IF(DAY .EQ. 274) GO TO 151
      IF(CONOPT(8) .EQ. 0) GO TO 146
      IF(DAY .NE. SGMD) GO TO 146
      WSG = WSG2
      SGRT = SGRT2
      GO TO 145
  151 MONTH = 1
      MDAY = 273
      AMRPM = 0.0
      AMPREC = 0.0
```

```
      AMBF = 0.0
      AMSE = 0.0
      AMSTF = 0.0
      AMRTF = 0.0
      WRITE(6,3) (TITLE(KTA), KTA = 1,20)
    3 FORMAT(1H1,10X,20A4)
      WRITE(6,4) (YTITLE(KTA), KTA = 1,20),YR1,YR2
    4 FORMAT(1H0,20A4,2X,13HWATER YEAR 19,I2,1H-,I2)
      WRITE(6,5)
    5 FORMAT(8H OCTOBER)
C  BEGIN DAY LOOP
  152 TDSF = 0.0
      IF(DAY.LT.151.OR.DAY.GT.265)  PET = 0.35*DPET(DAY)
      IF(DAY.GE.151.AND.DAY.LT.166) PET = 0.41*DPET(DAY)
      IF(DAY.GE.166.AND.DAY.LT.182) PET = 0.47*DPET(DAY)
      IF(DAY.GE.182.AND.DAY.LT.197) PET = 0.67*DPET(DAY)
      IF(DAY.GE.197.AND.DAY.LT.228) PET = 0.80*DPET(DAY)
      IF(DAY.GE.228.AND.DAY.LT.244) PET = 0.74*DPET(DAY)
      IF(DAY.GE.244.AND.DAY.LT.266) PET = 0.61*DPET(DAY)
      PETU = PET
      TFMAX = 0.0
      BMIR = BMTR
      IF(DAY .LT. NDTUZ) BMIR = BMTR/GFIE
      IF(CONOPT(15) .NE. 1) GO TO 322
      IF(DAY.LT.151.OR.DAY.GT.265)  REDX = 1.0
      IF(DAY.GE.151.AND.DAY.LT.166)  REDX = 0.35/0.41
      IF(DAY.GE.166.AND.DAY.LT.182)  REDX = 0.35/0.47
      IF(DAY.GE.182.AND.DAY.LT.197)  REDX = 0.35/0.67
      IF(DAY.GE.197.AND.DAY.LT.228)  REDX = 0.35/0.80
      IF(DAY.GE.228.AND.DAY.LT.244)  REDX =  0.35/0.74
      IF(DAY.GE.244.AND.DAY.LT.266)  REDX = 0.35/0.61
      IF(DAY .EQ. ISST1 .OR. DAY .EQ. ISST2)  TSST = TSST + AISS
      PWER = ALP4
      IF(DAY .LT. KDAY1 .OR. DAY .GT. KDAY2) PWER = ALP4/ALP5
  322 TDSSL = 0.0
C  EVAPOTRANSPIRATION ADJUSTMENTS
```

```
      IF(CONOPT(7) .NE. 1) GO TO 153                                    MAIN0358
      IF(DMXT(DAY) - 4.0*ELDIF .LT. 40.0) PET = 0.0                     MAIN0359
      IF(SPTW .GT. SPTWCC) PET = FFOR*PET                               MAIN0360
C   CALCULATION OF SNOW EVAPORATION                                     MAIN0361
      IF(DMNT(DAY) .GT. 32.0 .OR. SPTW .LE. DPSE(DAY)) GO TO 153        MAIN0362
      SE = DPSE(DAY)                                                    MAIN0363
      AMSNE = AMSNE + SE                                                MAIN0364
      SPTW = SPTW - SE                                                  MAIN0365
      IF(SFMD .GT. 0.0) SDEPTH = SDEPTH - SE/SFMD                       MAIN0366
  153 DO 202 HOUR = 1,24                                                MAIN0367
      IF((NSGRD .EQ. 0) .AND. (DRHP(DAY,HOUR) .NE. 0.0) .AND. (PET .EQ.MAIN0368
     1  PETU) .AND. (CONOPT(3) .EQ. 1)) PET = 0.5*PET                   MAIN0369
  154 IF(HCUR .EQ. SGRT + 1) RGPM = DRGPM(DAY)                          MAIN0370
      IF(HOUR .EQ. 9) HSE = (FWTR*PET)/12.0                             MAIN0371
      IF(HCUR .EQ.21) HSE = 0.0                                         MAIN0372
      PRH = RGPM*DRHP(DAY,HOUR)                                         MAIN0373
      AMPREC = AMPREC  + PRH                                            MAIN0374
C   ENTER SNOWMELT SUBROUTINE                                           MAIN0375
      IF(CONOPT(7) .EQ. 1) CALL SNOMEL(BDDFSM,SPTWCC,SPM,ELDIF,DAY,     MAIN0376
     1  SPBFLW, XDNFS,FFOR,FFSI,MRNSM,DSMGH,SDEPTH,STMD, PXCSA,HOUR,    MAIN0377
     2  SAX,SOFRF,OFRFIS,SOFRFI,AMFSIL,PRH,SPTW,TANSM,SPLW,SFMD,OFRF,   MAIN0378
     3  WT4AM,WT4PM,ASM,ASMRG,SASFX,SARAX,DMXT,DMNT,RICY,FIRR,TEH)      MAIN0379
      TEHCO = TEH - 4.0*ELDIF                                           MAIN0380
      IF(TEHCO .LE. 32.0) REDX = 0.0                                    MAIN0381
  155 AMRPM = AMRPM + PRH                                               MAIN0382
  156 TOFR = 0.0                                                        MAIN0383
      ARHF = 0.0                                                        MAIN0384
      ARSF = 0.0                                                        MAIN0385
      IF(CONOPT(15) .EQ. 1) TSST = TSST/EXP(PWER)                       MAIN0386
C   15 MINUTE ACCOUNTING AND ROUTING LOOP                               MAIN0387
      DO 187 PRD = 1,4                                                  MAIN0388
      PEBI = 0.0                                                        MAIN0389
      PPI = 0.0                                                         MAIN0390
      OFR = 0.0                                                         MAIN0391
      OFRIS = 0.0                                                       MAIN0392
      WI = 0.0                                                          MAIN0393
```

```
      WEIFS = 0.0
      PMEUZS = 0.0
      PMELZS = 0.0
      PMEIFS = 0.0
      PMEOFS = 0.0
      PEP = 0.25*PRH
      IF(CONOPT(2) .EQ. 1) CALL PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,PEP,
     1  PRH)
      IF(CONOPT(15) .NE. 1)  GO TO 325
      SPIX = (4.0*PEP)**ALP1
      SSPLH = BETA1*SPIX
      SSTO = BETA2*REDX*SPIX
  325 IF(PEP .GT. 0.0) GO TO 157
      IF(OFUS .GT. 0.0) GO TO 159
      IF(IFS .GT. 0.0) GO TO 170
      IF(NRTRI .GT. 0) GO TO 172
      TRHF = 0.0
      TRSF = 0.0
      IF(RHFO .GT. 0.0) GO TO 181
      GO TO 184
C  RAINFALL UPPER ZONE INTERACTION
  157 IF(PEP .GE. VINTCR) GO TO 158
      UZS = UZS + PEP*TPLR
      VINTCR = VINTCR - PEP
      PPI = 0.0
      PEBI = 0.0
      PMEUZS = PEP
      IF(OFUS .GT. 0.0) GO TO 159
      GO TO 170
  158 PPI = PEP - VINTCR
      UZS = UZS + VINTCR*TPLR
      VINTCR = 0.0
      LZSR = LZS/LZC
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZSR)
      IF(UZC .LT. 0.25) UZC = 0.25
      UZRX = 2.0*ABS(UZS/UZC - 1.0) + 1.0
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      FMR = (1.0/(1.0 + UZRX))**UZRX
      IF(UZS .GT. UZC) FMR = 1.0 - FMR
      PEBI = PPI*FMR
      PMEUZS = PEP - PEBI
      UZS = UZS + PPI - PEBI
C  LOWER ZCNE AND GRCUNDWATER INFILTRATION
  159 LZSR = LZS/LZC
      EID = 4.0*LZSR
      IF(LZSR .LE. 1.0) GO TO 160
      EID = 4.0 + 2.0*(LZSR - 1.0)
      IF(LZSR .LE. 2.0) GO TO 160
      EID = 6.0
  160 PEBI = PEBI + OFUS
      CMIR = C.25*SIAM*BMIR/(2.0**EID)
      CIVM = BIVF*2.0**LZSR
      IF(CIVM .LT. 1.0) CIVM = 1.0
      PEAI = PEBI*PEBI/(2.0*CMIR*CIVM)
      WI = PEBI*PEBI/(2.0*CMIR)
      IF(PEBI .GE. CMIR) WI = PEBI - 0.5*CMIR
      IF(PEBI .GE. CMIR*CIVM) PEAI = PEBI - 0.5*CMIR*CIVM
      WEIFS = WI - PEAI
      IF(PEBI .LE. OFUS) GO TO 161
      PMELZS = (PEBI - WI)*((PEBI - OFUS)/PEBI)
      PMEIFS = WEIFS*((PEBI - OFUS)/PEBI)
      PMEOFS = PEAI*((PEBI - OFUS)/PEBI)
  161 CCNTINUE
      IF((PEAI - OFUS) .GT. 0.0) GO TO 162
      EQD = (CFUS + PEAI)/2.0
      GO TO 163
  162 EQD = ECDF*((PEAI - OFUS)**0.6)
  163 IF((OFUS + PEAI) .GT. (2.0*EQD)) EQD = 0.5*(OFUS + PEAI)
      IF((OFUS + PEAI) .LE. 0.001) GO TO 164
      OFR = 0.25*OFRF*(((OFUS + PEAI)*0.5)**1.67)*((1.0 + 0.6*((OFUS +
     1  PEAI)/(2.0*EQD))**3.0)**1.67)
      IF(OFR .GT. (0.75*PEAI)) OFR = 0.75*PEAI
  164 IF(FIMP .EQ. 0.0) GO TO 168
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165 PEIS = PPI + OFUSIS                                                  MAIN0466
    IF((PEIS - OFUSIS) .GT. 0.0) GO TO 166                               MAIN0467
    EQDIS = (OFUSIS + PEIS)/2.0                                          MAIN0468
    GO TO 167                                                            MAIN0469
166 EQDIS = EQDFIS*((PEIS - OFUSIS)**0.6)                                MAIN0470
167 IF((OFUSIS + PEIS) .GT. (2.0*EQDIS)) EQDIS = 0.5*(OFUSIS + PEIS)     MAIN0471
    IF((OFUSIS + PEIS) .LE. 0.01) GO TO 168                              MAIN0472
    OFRIS = 0.25*OFRFIS*(((OFUSIS + PEIS)*0.5)**1.67)*((1.0 + 0.6*((     MAIN0473
   1  OFUSIS + PEIS)/(2.0*EQDFIS))**3.0)**1.67)                          MAIN0474
    IF(OFRIS .GT. PEIS) OFRIS = PEIS                                     MAIN0475
168 TOFR = TOFR + FPER*OFR + FIMP*OFRIS + PPI*FWTR                       MAIN0476
    OFUSIS = PEIS - OFRIS                                                MAIN0477
    CFUS = PEAI - OFR                                                    MAIN0478
    IF(OFUS .GE. 0.001) GO TO 169                                        MAIN0479
    LZS = LZS + OFUS                                                     MAIN0480
    OFUS = C.0                                                           MAIN0481
    OFRIS = OFRIS + OFUSIS                                               MAIN0482
    OFUSIS = 0.0                                                         MAIN0483
169 LZRX = 1.5*ABS(LZS/LZC - 1.0) + 1.0                                  MAIN0484
    FMR = (1.0/(1.0 + LZRX))**LZRX                                       MAIN0485
    IF(LZS .LT. LZC) FMR = 1.0 - FMR*(LZS/LZC)                           MAIN0486
    PLZS = FMR*(PEBI - WI)                                               MAIN0487
    PGW = (1.0 -FMR)*(PEBI - WI)*(1.0 - SUBWF)*FPER                      MAIN0488
    GWS = GWS + PGW                                                      MAIN0489
    BFNX = BFNX + PGW                                                    MAIN0490
    LZS = LZS + PLZS                                                     MAIN0491
    IFS = IFS + WEIFS*FPER                                               MAIN0492
170 SPIF = IFRL*IFS                                                      MAIN0493
    AMIF = AMIF + SPIF                                                   MAIN0494
    IFS = IFS - SPIF                                                     MAIN0495
    IF(IFS .GE. 0.0001) GO TO 171                                        MAIN0496
    LZS = LZS + IFS                                                      MAIN0497
    IFS = 0.0                                                            MAIN0498
171 UHFA(1) = FPER*OFR + PPI*FWTR + FIMP*OFRIS + SPIF                    MAIN0499
    SPDR = UHFA(1)                                                       MAIN0500
    IF(CONOPT(15).NE.1) GO TO 172                                        MAIN0501
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      TROVQ = BETA3*SPDR**ALP2
      TSST = TSST + SSTO
      IF(TROVQ .GT. TSST) TROVQ = TSST
      TSST = TSST - TROVQ
      IF(TSST .LT. 0.0) TSST = 0.0
      SCROV = BETA5*SPDR**BETA6
      USFA(1) = SSPLH + TROVQ + SCROV
C  ROUTING
  172 IF(CONOPT(12) .NE. 1) GO TO 173
      URHF = URHF + 0.25*UHFA(1)
      IF(CONOPT(15) .EQ. 1) URSF = URSF + 0.25*USFA(1)
      IF(PRD .NE. 4) GO TO 181
      UHFA(1) = URHF
      IF(CONOPT(15) .EQ. 1) USFA(1) = URSF
  173 TRHF = 0.0
      TRSF = 0.0
      KTRI = NCTRI
      IF(CONOPT(13) .EQ. 1) KTRI = NCSTRI
  174 URHF = UHFA(KTRI)
      IF(CONOPT(15) .EQ. 1) URSF = USFA(KTRI)
      IF(URHF.LE.0.0) GO TO 176
  175 TRHF = TRHF + URHF*CTRI(KTRI)
      IF(CONOPT(13) .EQ. 1 .AND. LSHFT .AND. KTRI .GE. 2) TRHF = TRHF +
     1  URHF*SATRI(KTRI - 1)
      UHFA(KTRI + 1) = URHF
      IF(CONOPT(15) .EQ. 1)   TRSF = TRSF + URSF*CTRI(KTRI)
      IF(CONOPT(13) .EQ. 1 .AND. LSHFT .AND. KTRI .GE. 2 .AND. CONOPT(15
     *) .EQ. 1) TRSF = TRSF +URSF*SATRI(KTRI - 1)
      IF(CONOPT(15) .EQ. 1) USFA(KTRI + 1) = URSF
C
C   PROGRAM ASSUMES THAT WHEN TRHF = 0.0 THEN TRSF = 0.0
      GO TO 177
  176 UHFA(KTRI+ 1) = 0.0
      IF(CONOPT(15) .EQ. 1)  USFA(KTRI + 1) = 0.0
  177 KTRI = KTRI - 1
      IF(KTRI .GE. 1) GO TO 174
  178 IF(URHF .LE. 0.0) GO TO 179
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      NRTRI = NCTRI                                                     MAIN0538
      IF(CONOPT(13) .EQ. 1) NRTRI = MXTRI                               MAIN0539
  179 NRTRI = NRTRI - 1                                                 MAIN0540
      UHFA(1) = 0.0                                                     MAIN0541
      USFA(1) = 0.0                                                     MAIN0542
      IF(CONOPT(13) .NE. 1) GO TO 180                                   MAIN0543
      NNSTRI = NCSTRI + 1                                               MAIN0544
      UHFA(NNSTRI) = 0.0                                                MAIN0545
      USFA(NNSTRI) = 0.0                                                MAIN0546
  180 URHF = 0.0                                                        MAIN0547
      URSF = 0.0                                                        MAIN0548
  181 IF(SRX .LE. CSRX) SRX = CSRX                                      MAIN0549
      RHF1 = TRHF - SRX*(TRHF - RHFO)                                   MAIN0550
      RHFO = RHF1                                                       MAIN0551
      IF(CONOPT(15) .EQ. 1) RSDF1 = TRSF - SRX*(TRSF - RSDFO)           MAIN0552
      IF(CONOPT(15) .EQ. 1) RSDFO = RSDF1                               MAIN0553
      IF(RHFO .LT. RHFMC) RHFO = 0.0                                    MAIN0554
      TFCFS = (4.0*RHF1 + CBF - HSE)*WCFS                               MAIN0555
      IF(CONOPT(13) .NE. 1) GO TO 182                                   MAIN0556
      IF(CONOPT(12) .EQ. 1 .AND. PRD .NE. 4) GO TO 182                  MAIN0557
      CALL RTVARY (CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCSTRI,EXQPV,LSHFT,MAIN0558
     1  TFCFS)                                                          MAIN0559
      DATE = MOD(DAY,MCAY)                                              MAIN0560
      IF(LSHFT) WRITE(6,6) DATE,HOUR,PRD,NCSTRI                         MAIN0561
    6 FORMAT(2X,I2,2X,I2,2X,I2,2X,20HHISTOGRAM CHANGES TO,1X,I2,1X,     MAIN0562
     1  8HELEMENTS)                                                     MAIN0563
  182 CONTINUE                                                          MAIN0564
      IF(TFCFS .LE. 0.5*CHCAP) SRX = CSRX                               MAIN0565
      IF((TFCFS .GT. 0.5*CHCAP) .AND. (TFCFS .LT. 2.0*CHCAP)) SRX = CSRXMAIN0566
     1  +(FSRX - CSRX)*((TFCFS - 0.5*CHCAP)/(1.5*CHCAP))**3             MAIN0567
      IF(TFCFS .GT. 2.0*CHCAP) SRX = FSRX                               MAIN0568
      IF(TFCFS .LE. TFMAX) GO TO 183                                    MAIN0569
      PRDF = PRD                                                        MAIN0570
      TDFP24 = HOUR                                                     MAIN0571
      IF(PRD .LE. 3) TDFP24 = (TDFP24 - 1.0) + 0.15*PRDF                MAIN0572
      TFMAX = TFCFS                                                     MAIN0573
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  183 ARHF = ARHF + RHF1                                                    MAIN0574
      IF(CONOPT(15) .EQ. 1) ARSF = ARSF + RSDF1                             MAIN0575
C   STORM OUTPUT REQUESTED BY CONOPT(1)                                     MAIN0576
  184 IF(CONOPT(1) .NE. 1) GO TO 186                                        MAIN0577
      IF(DAY .NE. CDSDR) GO TO 186                                          MAIN0578
      IF(HOUR .EQ. 1 .AND. PRD .EQ. 1) WRITE(6,7)                           MAIN0579
    7 FORMAT(1H//,21X,19HRAINFALL DEPOSITION,12X,16HMOISTURE STORAGE,      MAIN0580
     1  14X,17HSTREAMFLOW ORIGIN,6X,14HSTREAM OUTFLOW/2X,116HDY HR PD RAMAIN0581
     2IN    EUZS    ELZS    EIFS    EOFS       UZS     LZS     IFS     OFS     SMAIN0582
     3POF    SPIF    SPBF    SPTF   INCHES     CFS)                          MAIN0583
      CATE = MOD(DAY,MCAY)                                                  MAIN0584
      CFS = OFUS*FPER + OFUSIS*FIMP                                         MAIN0585
      SPOF = CFR*FPER + OFRIS*FIMP + PPI*FWTR                               MAIN0586
      SPBF = 0.25*(CBF-HSE)                                                 MAIN0587
      SPTF = SPDR + SPBF                                                    MAIN0588
      SPDR = 0.0                                                            MAIN0589
      IF(RHFO .LE. 0.0) TFCFS = (CBF - HSE)*WCFS                            MAIN0590
      RSPTF = 0.25*TFCFS/WCFS                                               MAIN0591
      WRITE(6,8) DATE,HOUR,PRD,PEP,PMEUZS,PMELZS,PMEIFS,PMEOFS,UZS,LZS      MAIN0592
    8 FORMAT(2X,I2,1X,I2,1X,I1,5(1X,F6.4),2X,4(F7.4),2X,5(1X,F6.4),1X,      MAIN0593
     1  F7.1)                                                               MAIN0594
      IF(HOUR .EQ. 24 .AND. PRD .EQ. 4) GO TO 185                           MAIN0595
      GO TO 186                                                             MAIN0596
  185 NDSDP = NDSDP + 1                                                     MAIN0597
      IF(NDSDR .EQ. NDSDP) GO TO 186                                        MAIN0598
      CALL CAYNXT(CDSDR,DPY)                                                MAIN0599
  186 CONTINUE                                                              MAIN0600
      IF(VINTCR .LT. 0.25*VINTMR) VINTCR = VINTCR + DPET(DAY)/96.0          MAIN0601
  187 CONTINUE                                                              MAIN0602
C   END OF 15 MINUTE LOCP                                                   MAIN0603
      IF(CONOPT(5) .NE. 1) GO TO 197                                        MAIN0604
C   HOURLY OVERLAND FLOW AND RAINFALL SORTING                               MAIN0605
      IF(TOFR .LE. 0.0) GO TO 193                                           MAIN0606
      KT20 = 20                                                             MAIN0607
  188 IF(KT20 .LT. 1) GO TO 192                                             MAIN0608
      IF(TOFR .GT. T20OFH(KT20)) GO TO 189                                  MAIN0609
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      GO TO 190
  189 T20OFH(KT20+1) = T20OFH(KT20)
      GO TO 191
  190 T20OFH(KT20+1) = TOFR
      GO TO 193
  191 KT20 = KT20 - 1
      GO TO 188
  192 T20OFH(1) = TOFR
  193 IF(PRH .LE. 0.0) GO TO 197
      KT20 = 20
  194 IF(KT20 .LT. 1) GO TO 196
      T20PRH(KT20 + 1) = PRH
      IF(PRH .GT. T20PRH(KT20)) GO TO 195
      GO TO 197
  195 T20PRH(KT20+1) = T20PRH(KT20)
      KT20 = KT20 - 1
      GO TO 194
  196 T20PRH(1) = PRH
C  ADDING GROUNDWATER FLOW
  197 CBF = GWS*BFRL*(1.0 + BFNRL*BFNX)
      GWS = GWS - CBF
      AMBF = AMBF + CBF
      THGR = ARHF + CBF
      IF(HSE .GT. THGR) HSE = THGR
      AMSE = AMSE + HSE
      IF(CONOPT(15) .EQ. 1) TSSF(HOUR) = ARSF
      THSF(HOUR) = (THGR - HSE)*WCFS
      TDSF = TDSF + THSF(HOUR)
      IF(CONOPT(15) .EQ. 1) TDSSL = TDSSL + TSSF(HOUR)
C  DRAINING OF UPPER ZONE STORAGE
      UZINFX = (UZS/UZC) - (LZS/LZC)
      IF(UZINFX .LE. 0.0) GO TO 198
      LZSR = LZS/LZC
      UZINLZ = 0.003*BMIR*UZC*UZINFX**3.0
      IF(UZINLZ .GT. UZS) UZINLZ = UZS
      UZS = UZS - UZINLZ
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      LZRX = 1.5*ABS(LZSR - 1.0) + 1.0
      FMR = (1.0/(1.0 + LZRX))**LZRX
      IF(LZS .LT. LZC) FMR = 1.0 - FMR*LZSR
      PGW = (1.0-FMR)*UZINLZ*(1.0 - SUBWF)*FPER
      PLZS = FMR*UZINLZ
      LZS = LZS + PLZS
      GWS = GWS + PGW
      BFNX = BFNX + PGW
C  4 PM ADJUSTMENTS OF VARIOUS VALUES
  198 IF(HOUR .NE. 16) GO TO 202
      AEX90 = 0.9*(AEX90 + PET)
      AEX96 = 0.96*(AEX96 + PET)
C  INFILTRATICN CORRECTION
      SIAM = (AEX96/AETX)**SIAC
      IF(SIAM .LT. 0.33) SIAM = 0.33
      BFNX = C.97*BFNX
      IF(PET .EQ. 0.0) GO TO 202
C  EVAP-TRANS LOSS FRCM GROUNDWATER
      GWET = GWS*GWETF*PET*FPER
      GWS = GWS - GWET
      BFNX = BFNX - GWET
      IF(BFNX .LT. 0.0) BFNX = 0.0
      AMPET = AMPET + PET
      IF(PET .GE. UZS) GO TO 199
      UZS = UZS - PET
      AMNET = AMNET + PET
      GO TO 202
  199 PET = PET - UZS
      AMNET = AMNET + UZS
      UZS = 0.0
      LZSR = LZS/LZC
      IF(PET .GE. ETLF*LZSR) GO TO 200
      SET = PET*(1.0 - PET/(2.0*ETLF*LZSR))
      GO TO 201
  200 SET = 0.5*ETLF*LZSR
  201 LZS = LZS - SET
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      AMNET = AMNET + SET                                               MAIN0682
  202 CCNTINUE                                                          MAIN0683
C  END OF HOUR LOOP                                                     MAIN0684
      DSSF(DAY) = TDSF/24.0                                             MAIN0685
      IF(CONOPT(11) .EC. 1) DSSF(DAY) = DSSF(DAY) + DDIW(DAY)           MAIN0686
      IF(CONOPT(15) .NE. 1) GO TO 203                                   MAIN0687
      DSSE(CAY) = TDSSL                                                 MAIN0688
      SCOUR(DAY) = BETA4*DRSF(DAY)**ALP3                                MAIN0689
      DSSL(DAY) = SCCUR(DAY) + DSSE(DAY)                                MAIN0690
  203 AMRTF = AMRTF + CRSF(DAY)                                         MAIN0691
      AMSTF = AMSTF + CSSF(CAY)                                         MAIN0692
      IF(CONOPT(6) .EQ. 1) EDLZS(DAY) = LZS                             MAIN0693
C  STORE ERRORS AND FLCW DURATION                                       MAIN0694
      IF(CONOPT(4) .NE. 1) GO TO 204                                    MAIN0695
      ERR = DSSF(DAY) - DRSF(DAY)                                       MAIN0696
      IF(DRSF(DAY) .LT. 1.0) KRFMI = 1.0                                MAIN0697
      IF(DRSF(DAY) .GT. 1.0) KRFMI= 2.0*ALOG(DRSF(DAY)) + 2.0           MAIN0698
      CRFMI(KRFMI) = CRFMI(KRFMI) + 1.0                                 MAIN0699
      SERR(KRFMI) = SERR(KRFMI) + ERR                                   MAIN0700
      SERA(KRFMI) = SERA(KRFMI) + ABS(ERR)                              MAIN0701
      SQER(KRFMI) = SQER(KRFMI) + ERR*ERR                               MAIN0702
      SESF(KRFMI) = 0.C                                                 MAIN0703
      IF(CRFMI(KRFMI) .GT. 1.0) SESF(KRFMI) = SQRT(ABS((SQER(KRFMI) -   MAIN0704
     1  SERR(KRFMI)**2/CRFMI(KRFMI))/(CRFMI(KRFMI) - 1.0)))             MAIN0705
  204 IF(DAY .EQ. 366) MDAY = 337                                       MAIN0706
      DATE = MOD(DAY,MDAY)                                              MAIN0707
      IF(TFMAX .LE. RMPF) GO TO 206                                     MAIN0708
      WRITE(6,9) DATE, (THSF(HOUR),HOUR=1,12)                           MAIN0709
    9 FORMAT(1H/,1X/,1X,I4,2X,2HAM,1X,6F8.1,3X,6F8.1)                   MAIN0710
      WRITE(6,10) (THSF(HOUR),HOUR=13,24), DSSF(DAY)                    MAIN0711
   10 FCRMAT(1HJ,6X,2HPM,1X,6F8.1,3X,7F8.1)                             MAIN0712
      IF(TDFP24 .LT. 12.0) GO TO 205                                    MAIN0713
      TDFP12 = TDFP24 - 12.0                                            MAIN0714
      WRITE(6,11) TFMAX, TDFP12                                         MAIN0715
   11 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,  MAIN0716
     1  4HP.M.)                                                         MAIN0717
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      GO TO 206                                                        MAIN0718
  205 WRITE(6,12) TFMAX,TDFP24                                         MAIN0719
   12 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X, MAIN0720
     1  4HA.M.)                                                        MAIN0721
  206 IF(CONOPT(7) .EQ. 1 .AND. SDEPTH .GT. 0.0) WRITE(6,13)DATE,      MAIN0722
     1SDEPTH,STMD,SAX,TANSM,SPLW                                       MAIN0723
   13 FORMAT(3X,I4,2X,7HSDEPTH=,F8.2,2X,5HSTMD=,F6.2,2X,4HSAX=,F6.2,   MAIN0724
     1  2X,6HTANSM=,F6.2,2X,5HSPLW=,F6.2)                              MAIN0725
C  MONTHLY SUMMARY STORAGE                                             MAIN0726
      IF(DAY .NE. MEDWY(MONTH)) GO TO 220                              MAIN0727
      TMSTF(MONTH) = AMSTF                                             MAIN0728
      AMSTF = 0.0                                                      MAIN0729
      TMRTF(MONTH) = AMRTF                                             MAIN0730
      AMRTF = 0.0                                                      MAIN0731
      EMBFNX(MONTH) = BFNX                                             MAIN0732
      TMPREC(MONTH) = AMPREC                                           MAIN0733
      AMPREC = 0.0                                                     MAIN0734
      TMRPM(MONTH) = AMRPM                                             MAIN0735
      AMRPM = 0.0                                                      MAIN0736
      TMBF(MONTH) = AMBF                                               MAIN0737
      AMBF = 0.0                                                       MAIN0738
      TMIF(MONTH) = AMIF                                               MAIN0739
      AMIF = 0.0                                                       MAIN0740
      TMSE(MONTH) = AMSE                                               MAIN0741
      AMSE = 0.0                                                       MAIN0742
      TMPET(MONTH) = AMPET                                             MAIN0743
      AMPET = 0.0                                                      MAIN0744
      TMNET(MONTH) = AMNET                                             MAIN0745
      AMNET = 0.0                                                      MAIN0746
      TMSNE(MONTH) = AMSNE                                             MAIN0747
      AMSNE = 0.0                                                      MAIN0748
      TMFSIL(MONTH) = AMFSIL                                           MAIN0749
      AMFSIL = 0.0                                                     MAIN0750
      EMGWS(MONTH) = GWS                                               MAIN0751
      UZC = SUZC*AEX90 + BUZC*EXP(-2.7*LZS/LZC)                        MAIN0752
      IF(UZC .LT. 0.25) UZC = 0.25                                     MAIN0753
```

```
      EMUZC(MONTH) = UZC
      EMUZS(MONTH) = UZS
      EMSIAM(MONTH) = SIAM
      EMLZS(MONTH) = LZS
      EMIFS(MONTH) = IFS
      IF(MONTH .EQ. 5) MEDWY(5) = 59
      MDAY = MEDWY(MONTH)
  207 IF(MONTH .NE. 0) GO TO (208,209,210,211,212,213,214,215,216,217,
     1  218,219),MONTH
  208 WRITE(6,14)
   14 FORMAT(1H/,8HNOVEMBER)
      GO TO 219
  209 WRITE(6,15)
   15 FORMAT(1H/,8HDECEMBER)
      GO TO 219
  210 WRITE(6,16)
   16 FORMAT(1H/,7HJANUARY)
      GO TO 219
  211 WRITE(6,17)
   17 FORMAT(1H/,8HFEBRUARY)
      GO TO 219
  212 WRITE(6,18)
   18 FORMAT(1H/,5HMARCH)
      GO TO 219
  213 WRITE(6,19)
   19 FORMAT(1H/,5HAPRIL)
      GO TO 219
  214 WRITE(6,20)
   20 FORMAT(1H/,3HMAY)
      GO TO 219
  215 WRITE(6,21)
   21 FORMAT(1H/,4HJUNE)
      GO TO 219
  216 WRITE(6,22)
   22 FORMAT(1H/,4HJULY)
      GO TO 219
```

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  217 WRITE(6,23)                                                       MAIN0790
   23 FORMAT(1H/,6HAUGUST)                                              MAIN0791
      GO TO 219                                                         MAIN0792
  218 WRITE(6,24)                                                       MAIN0793
   24 FORMAT(1H/,9HSEPTEMBER)                                           MAIN0794
  219 MONTH = MONTH + 1                                                 MAIN0795
  220 CALL DAYNXT(DAY,DPY)                                              MAIN0796
      IF(DAY .NE. 274) GO TO 152                                        MAIN0797
C  END OF DAY LOOP                                                      MAIN0798
  221 CONTINUE                                                          MAIN0799
  222 WRITE(6,25) (TITLE(KTA), KTA=1,20,1)                              MAIN0800
   25 FORMAT(1H1,10X,20A4)                                              MAIN0801
      WRITE(6,26) (YTITLE(KTA),KTA=1,15,1),YR1,YR2                      MAIN0802
   26 FORMAT(1H/,15A4,3X,14HWATER YEAR  19,I2,1H-,I2,7X,                MAIN0803
     1  29H KENTUCKY WATERSHED MODEL     )                              MAIN0804
C  ANNUAL SUMMARY                                                       MAIN0805
      SATFV = 0.0                                                       MAIN0806
      RATFV = 0.0                                                       MAIN0807
      APREC = 0.0                                                       MAIN0808
      ABFV = 0.0                                                        MAIN0809
      ARPM = 0.0                                                        MAIN0810
       ASEV = 0.0                                                       MAIN0811
      ANET = 0.0                                                        MAIN0812
      APET = 0.0                                                        MAIN0813
      AIFV = 0.0                                                        MAIN0814
      ASE = 0.0                                                         MAIN0815
      AFSIL = 0.0                                                       MAIN0816
      DO 223 MONTH = 1,12                                               MAIN0817
      SATFV = SATFV + TMSTF(MONTH)                                      MAIN0818
      RATFV = RATFV + TMRTF(MONTH)                                      MAIN0819
      APREC = APREC + TMPREC(MONTH)                                     MAIN0820
      ABFV = ABFV + TMBF(MONTH)                                         MAIN0821
      ARPM = ARPM + TMRPM(MONTH)                                        MAIN0822
      ASEV = ASEV + TMSE(MONTH)                                         MAIN0823
      ANET = ANET + TMNET(MONTH)                                        MAIN0824
      APET = APET + TMPET(MONTH)                                        MAIN0825
```

```
      AIFV = AIFV + TMIF(MONTH)
      ASE = ASE + TMSNE(MONTH)
  223 AFSIL = AFSIL + TMFSIL(MONTH)
      IF(CONOPT(14) .NE. 1) GO TO 224
      WRITE(6,27)
   27 FCRMAT(1H//44X,20HRECORDED       FLOWS)
      CALL CAYOUT(DRSF,MEDWY,DPY)
      WRITE(6,28)
   28 FCRMAT(1H//44X,23HSYNTHESIZED       FLOWS)
  224 CALL DAY OUT(DSSF, MEDWY, DPY)
      WRITE(6,29) (TMSTF(KWD), KWD=1,12), SATFV
   29 FORMAT(1X, 9HSYNTHETIC,3X,12F8.1,2X,F10.1,2X,3HSFD)
      DO 225 MONTH = 1,12
  225 TMSTFI(MCNTH) = (TMSTF(MONTH))/VWIN
      SATFVI = SATFV/VWIN
      WRITE(6,30) (TMSTFI(KWD), KWD=1,12),SATFVI
   30 FCRMAT(1X,5HTOTAL,8X,12F8.3,4X,F7.3,2X,6HINCHES)
      DO 226 MONTH = 1,12
      TMOF(MONTH) = TMSTFI(MONTH)- TMIF(MONTH) - TMBF(MONTH) +
     1  TMSE(MONTH)
  226 IF(TMOF(MONTH) .LT. 0.0) TMOF(MONTH) = 0.0
      AOFV = SATFVI - AIFV - ABFV + ASEV
      IF(AOFV .LT. 0.0) AOFV = 0.0
      WRITE(6,31) (TMOF(KWD), KWD=1,12), AOFV
   31 FCRMAT(1X,8HOVERLAND ,5X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,32) (TMIF(KWD), KWD=1,12),AIFV
   32 FCRMAT(1X,9HINTERFLOW,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,33) (TMBF(KWD), KWD=1,12),ABFV
   33 FORMAT(1X,4HBASE,9X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,34) (TMSE(KWD), KWD=1,12), ASEV
   34 FORMAT(1X,9HSTRM EVAP,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      IF(CONOPT(9) .EQ. 0) GO TO 227
      WRITE(6,35) (TMRTF(KWD), KWD=1,12),RATFV
   35 FCRMAT(1X,8HRECORDED,4X,12F8.1,2X,F10.1,2X,3HSFD)
      RATFVI = RATFV/VWIN
      WRITE(6,36) RATFVI
```

```
 36 FORMAT(112X,F9.2,2X,6HINCHES)                                       MAIN0862
227 WRITE(6,37) (TMPREC(KWD), KWD=1,12),APREC                           MAIN0863
 37 FORMAT( 1X,6HPRECIP,7X,12F8.2,3X,F8.2,2X,6HINCHES)                  MAIN0864
    IF(CONOPT(7) .EQ.1) WRITE(6,38) (TMRPM(KWD), KWD=1,12),ARPM         MAIN0865
 38 FORMAT(1X,9HRAIN+MELT,4X,12F8.2,3X,F8.2,2X,6HINCHES)                MAIN0866
    IF(CONOPT(7) .EQ.1) WRITE(6,39) (TMSNE(KWD), KWD=1,12),ASE          MAIN0867
 39 FORMAT(1X,11HSURSNOWEVAP,3X,12F8.3,3X,F7.3,2X,6HINCHES)             MAIN0868
    IF(CONOPT(7) .EQ.1) WRITE(6,40) (TMFSIL(KWD), KWD=1,12),AFSIL       MAIN0869
 40 FORMAT(1X,11HINTSNOWLOSS,3X,12F8.3,3X,F7.3,2X,6HINCHES)             MAIN0870
    WRITE(6,41) (TMNET(KWD), KWD=1,12),ANET                             MAIN0871
 41 FORMAT(1X,12HEVP/TRAN-NET,2X,12F8.3,3X,F7.3,2X,6HINCHES)            MAIN0872
    WRITE(6,42) (TMPET(KWD), KWD=1,12),APET                             MAIN0873
 42 FORMAT(3X,10H-POTENTIAL,2X,12F8.3,3X,F7.3,2X,6HINCHES)              MAIN0874
    WRITE(6,43) (EMUZS(KWD), KWD=1,12)                                  MAIN0875
 43 FORMAT(1X,12HSTORAGES-UZS,2X,12F8.3,12X,6HINCHES)                   MAIN0876
    WRITE(6,44) (EMLZS(KWD), KWD=1,12)                                  MAIN0877
 44 FORMAT(10X,3HLZS,2X,12F8.3,12X,6HINCHES)                            MAIN0878
    WRITE(6,45) (EMIFS(KWD), KWD=1,12)                                  MAIN0879
 45 FORMAT(10X,3HIFS,2X,12F8.3,12X,6HINCHES)                            MAIN0880
    WRITE(6,46) (EMGWS(KWD), KWD=1,12)                                  MAIN0881
 46 FORMAT(10X,3HGWS,2X,12F8.3,12X,6HINCHES)                            MAIN0882
    WRITE(6,47) (EMUZC(KWD), KWD=1,12)                                  MAIN0883
 47 FORMAT(1X,12HINDICES- UZC,2X,12F8.3)                                MAIN0884
    WRITE(6,48) (EMBFNX(KWD), KWD=1,12)                                 MAIN0885
 48 FORMAT(9X,4HBFNX,2X,12F8.3)                                         MAIN0886
    WRITE(6,49) (EMSIAM(KWD), KWD=1,12)                                 MAIN0887
 49 FORMAT(9X,4HSIAM,2X,12F8.3)                                         MAIN0888
    IF(CONOPT(7) .NE. 1) SPM = 1.0                                      MAIN0889
    AMBER = (LZS - BYLZS + IFS - BYIFS)*FPER + (UZS - BYUZS + GWS -     MAIN0890
   1  BYGWS)*(1.0 - FWTR) + SATFV/VWIN + ANET*FPER + ASEV - APREC       MAIN0891
   2  + ASE + AFSIL - ((SPM - 1.0)/SPM)*ASM                             MAIN0892
    WRITE(6,50) AMBER                                                   MAIN0893
 50 FORMAT(1H/7HBALANCE,5X,F10.4,2X,6HINCHES)                           MAIN0894
    IF(CONOPT(7) .NE. 1) GO TO 228                                      MAIN0895
    WRITE(6,51) ASM, ASMRG                                              MAIN0896
 51 FORMAT(1H/,13HCHECK ON SNOW,5X,F10.4,5X,F10.4)                      MAIN0897
```

```
      ASM = C.0
      ASMRG = 0.0
  228 CCNTINUE
      IF(CONOPT(4) .NE. 1) GO TO 232
      WRITE(6,52)
   52 FCRMAT(1H1,10X,35HDAILY FLOW DURATION AND ERROR TABLE)
      WRITE(6,53)
   53 FCRMAT(1H/,10X,13HFLOW INTERVAL,5X,5HCASES,3X,8HAV.ERROR,3X,
     1 16H AVR. ABS. ERROR,3X,14HSTANDARD ERROR)
      SSESF = 0.0
      SSERA = 0.0
      SSERR = 0.0
      ACRFMI = 0.0
      DO 230 KRFMI = 1,22
      IF(KRFMI .EQ. 1) ETIBF = 0.0
      IF(KRFMI .EQ. 2) ETIBF = 1.0
      FKRFMI = KRFMI
      IF(KRFMI .GT. 2) ETIBF = EXP((FKRFMI/2.0) - 1.0)
      CCRFMI = CRFMI(KRFMI)
      IF(CCRFMI .EQ. 0.0) WRITE(6,54) ETIBF, CCRFMI
   54 FORMAT(1X,13X,F8.1,1H-,F9.1,F12.1,5X,F8.2,5X,F8.2)
      IF(CCRFMI .EQ. 0.0) GO TO 229
      SERAV = SERA(KRFMI)/CCRFMI
      SERRV = SERR(KRFMI)/CCRFMI
      IF(CCRFMI .EQ. 1) WRITE(6,54) ETIBF,CCRFMI,SERRV,SERAV
      IF(CCRFMI .NE. 1) WRITE(6,54) ETIBF,CCRFMI,SERRV,SERAV,
     1SESF(KRFMI)
  229 ACRFMI = ACRFMI + CRFMI(KRFMI)
      IF(ACRFMI .EQ. 0.0) GO TO 230
      SSERR= SSERR + SERR(KRFMI)
      SSERRV= SSERR/ACRFMI
      SSERA = SSERA + SERA(KRFMI)
      SSERAV = SSERA/ACRFMI
  230 SSESF = SSESF + SESF(KRFMI)
      WRITE(6,55) ACRFMI,SSERRV,SSERAV,SSESF
   55 FCRMAT(1H/,22X,F9.1,F12.1,5X,F8.2,5X,F8.2)
```

```
      FDPY = DPY
      SADF = SATFV/FDPY
      RADF = RATFV/FDPY
      RA1 = 0.0
      RA2 = 0.0
      RA3 = 0.0
      DO 231 DAY = 1,DPY
      DRAF = DRSF(DAY) - RADF
      DSAF = DSSF(DAY) - SADF
      RA1 = RA1 + DRAF*DRAF
      RA2 = RA2 + DSAF*DSAF
  231 RA3 = RA3 + DRAF*DSAF
      DFCC= RA3/SQRT(RA1*RA2)
      WRITE(6,56) DFCC
   56 FORMAT(1H/,10X,31HCORRELATION COEFFICIENT (DAILY),3X,F10.4)
  232 CONTINUE
      IF(CONOPT(5) .NE. 1) GO TO 233
C  OUTPUT MAXIMUM RUNOFF, PRECIPITATION AT END OF YEARS
      WRITE(6,57)
   57 FORMAT(1H/,10X,58HTWENTY HIGHEST CLOCKHOUR RAINFALL EVENTS IN THE
     1WATER YEAR)
      WRITE(6,58) (T20PRH(KT20), KT20=1,20)
   58 FORMAT(1H/,5X,20F6.3)
      WRITE(6,59)
   59 FORMAT(1H/,10X,70HTWENTY HIGHEST CLOCKHOUR OVERLAND FLOW RUNOFF EV
     1ENTS IN THE WATER YEAR)
      WRITE(6,58) (T20OFH(KT20), KT20=1,20)
  233 CONTINUE
      IF(CONOPT(6) .EQ. 0) GO TO 234
      WRITE(6,99)
   99 FORMAT(1H1,30X,27HDAILY SOIL MOISTURE OUTPUT )
      CALL DAYOUT(EDLZS,MEDWY,DPY)
  234 CONTINUE
      IF(CONOPT(15).NE.1) GO TO 399
      WRITE(6,350)
  350 FORMAT(1H1,35X,32HDAILY SHEET EROSION LOSS IN TONS//)
```

```
      CALL DAYOUT(DSSE,MEDWY,DPY)
      WRITE(6,352)
  352 FORMAT(1H1,37X,27HDAILY CHANNEL SCOUR IN TONS//)
      CALL DAYCUT(SCCUR,MEDWY,DPY)
      WRITE(6,354)
  354 FCRMAT(1H1,32X,39HCAILY SYNTHESIZED SEDIMENT LOAD IN TONS//)
      CALL DAYOUT(DSSL,MEDWY,DPY)
      IF(CONOPT(16).NE.1) GO TO 399
      WRITE(6,356)
  356 FCRMAT(1H1,33X,36HDAILY RECORDED SEDIMENT LOAD IN TCNS//)
      CALL CAYOUT(DRSL,MEDWY,DPY)
  357 RATSV = 0.0
      SATSV = 0.0
      DO 236 CAY = 1,DPY
      RATSV = RATSV + DRSL(DAY)
  236 SATSV = SATSV + DSSL(DAY)
      FDPY = CPY
      RSX1 = C.0
      RSX2 = 0.0
      RSX3 = C.0
      RADSL = RATSV/FDPY
      SADSL = SATSV/FDPY
      DO 238 CAY = 1,DPY
      DRASL = DRSL(DAY) - RADSL
      DSASL = DSSL(DAY) - SADSL
      RSX1 = RSX1 + DRASL*DRASL
      RSX2 = RSX2 + CSASL*DSASL
  238 RSX3 = RSX3 + DRASL*DSASL
      DSCC = RSX3/ SQRT(RSX1*RSX2)
      WRITE(6,240) DSCC
  240 FORMAT(1H/,10X,30HCORRELATION COEFFICIENT(DAILY),3X,F10.4)
  399 IF(NYSQ.LE.NYSC) GO TO 400
      IF(CONOPT(10) .EQ. 1) GO TO 100
      GO TO 117
  400 STOP
      END
```

```
C
C     SLBROUTINE DAYNXT
C
      SUBROUTINE DAYNXT(DAY,DPY)                                        DYNX0001
C  DETERMINES NUMBER OF NEXT DAY OF THE YEAR                            DYNX0002
      INTEGER  DAY,DPY                                                  DYNX0003
      CAY = CAY + 1                                                     DYNX0004
      IF(DAY .EQ. 366) CAY = 1                                          DYNX0005
      IF(DAY .EQ. 60 .AND. DPY .EQ. 366) DAY = 366                      DYNX0006
      IF(CAY .EQ. 367) CAY = 60                                         DYNX0007
      RETURN                                                            DYNX0008
      END                                                               DYNX0009
C
C
C
C
C     SUBROUTINE CAYCUT
      SUBROUTINE DAYCUT(VDCY,MEDWY,DPY)                                 DYOT0001
C  PRINTS TABLE OF DAILY VALUES                                         DYOT0002
      DIMEKSICN  MEDWY(12),VDCY(366),VDMD(12)                           DYOT0003
      INTEGER  DATE,CAY,DPY                                             DYOT0004
  100 WRITE(6,1)                                                        DYOT0005
    1 FCRMAT(7X,3HDAY,7X,3HOCT,5X,3HNOV,5X,3HDEC,5X,3HJAN,5X,3HFEB,5X,   DYOT0006
     1  3HMAR,5X,3HAPR,5X,3HMAY,5X,3HJUN,5X,3HJUL,5X,3HAUG,5X,4HSEPT)   DYOT0007
      MEDWY(3) = 0                                                      DYOT0008
      DO 104 CATE = 1,28,1                                              DYOT0009
      IF(MOD(CATE,5) .NE. 1) GO TO 102                                  DYOT0010
      DO 101 KMO = 1,12                                                 DYOT0011
      CAY = MEDWY(KMC) + DATE                                           DYOT0012
  101 VDMD(KMC) = VDCY(DAY)                                             DYOT0013
      WRITE(6,2) DATE,VDMD(12),(VDMD(KWD), KWD=1,11)                    DYOT0014
    2 FORMAT(1HO,3X,I6,3X,12F8.1)                                       DYOT0015
      GO TO 104                                                         DYOT0016
  102 DO 103 KMO = 1,12                                                 DYOT0017
      DAY = MEDWY(KMC) + DATE                                           DYOT0018
  103 VDMD(KMC) = VDCY(DAY)                                             DYOT0019
```

```
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD), KWD = 1,11)
    3 FORMAT(1X,3X,I6,3X,12F8.1)
  104 CONTINUF
      IF(DPY .NE. 366) GO TO 106
      DATE = 29
      VDCY(60) = VDCY(366)
      DO 105 KMO = 1,12
      DAY = MEDWY(KMC) + DATE
  105 VDMD(KMC) = VDCY(DAY)
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD), KWD=1,11)
      GO TO 1C7
  106 CONTINUE
      WRITE(6,4) VDCY(302),VDCY(333),VDCY(363),VDCY(29),VDCY(88),
     1VDCY(119),VDCY(149),VDCY(180),VDCY(210),VDCY(241),VDCY(272)
    4 FCRMAT(1X,7X,2H29,3X,4F8.1,8X,7F8.1)
  107 CONTINUE
  108 WRITE(6,5) VDCY(303),VDCY(334),VDCY(364),VDCY(30),VDCY(89),
     1VDCY(120),VDCY(150),VDCY(181),VDCY(211),VDCY(242),VDCY(273)
    5 FORMAT(1X,7X,2H30,3X,4F8.1,8X,7F8.1)
      WRITE(6,6) VDCY(304),VDCY(365),VDCY(31),VDCY(90),VDCY(151),
     1VDCY(212),VDCY(243)
    6 FCRMAT(1H/,7X,2H31,3X,F8.1,8X,2F8.1,8X,F8.1,8X,F8.1,8X,2F8.1)
      MEDWY(3) = 365
      RETURN
      END
C
C
C     SUBROUTINE PREPRD
C
      SUBROUTINE PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,PEP,PRH)
C  DIVIDES HOURLY PRECIPITATION TOTALS AMONG PERIODS FOR SMALL BASINS
      DIMENSICN DRHP(366,24), PE4P(4)
      INTEGER DAY,DPY,HOUR,PRD
      PEP = 0.0
      IF(PRH .EQ. 0.0) RETURN
      IF(PRD .EQ. 1) GO TO 100
```

```
      PEP = PE4P(PRD)
      RETURN
  100 LHOUR = HOUR - 1
      LCAY = CAY
      IF(LHOUR .GE. 1) GO TO 101
      LHOUR = 24
      LCAY = CAY - 1
      IF(LCAY .EQ. 0) LDAY = 365
      IF(LCAY .EQ. 365) LDAY = 59
      IF(LDAY .EQ. 59 .AND. DPY .EQ. 366) LDAY = 366
  101 PRLH = RGPM*DRHP(LCAY,LHOUR)
      NHOUR = HOUR + 1
      NCAY = CAY
      IF(NHOUR .LE. 24) GO TO 102
      NHOUR = 1
      CALL CAYNXT(NDAY,DPY)
  102 PRNH = RGPM*DRHP(NDAY,NHOUR)
      IF(PRH .GT. PRLH .AND. PRH .GT. PRNH) GO TO 103
      GO TO 104
  103 PE4P(1) = 0.10
      PE4P(2) = 0.28
      PE4P(3) = 0.46
      PE4P(4) = 0.16
      GO TO 108
  104 IF(PRH .LT. PRLH .AND. PRH .LT. PRNH) GO TO 105
      GO TO 106
  105 PE4P(1) = 0.28
      PE4P(2) = 0.10
      PE4P(3) = 0.16
      PE4P(4) = 0.46
      GO TO 108
  106 IF(PRNH .GE. PRLH) GO TO 107
      PE4P(1) = 0.46
      PE4P(2) = 0.16
      PE4P(3) = 0.28
      PE4P(4) = 0.10
```

```
      GO TO 1C8                                                         PREP0044
  107 PE4P(1) = 0.10                                                    PREP0045
      PE4P(2) = 0.28                                                    PREP0046
      PE4P(3) = 0.16                                                    PREP0047
      PE4P(4) = 0.46                                                    PREP0048
  108 DO 109 KPRD = 1,4                                                 PREP0049
  109 PE4P(KPRD) = PE4P(KPRD)*PRH                                       PREP0050
      PEP = PE4P(1)                                                     PREP0051
      RETURN                                                            PREP0052
      END                                                               PREP0053
C
C
C
C
C     SUBROUTINE RTVARY
      SUBRCUTINE RTVARY(CTRI,SATRI,BTRI,CHCAP,NBTRI,MXTRI,NCTRI,EXQPV,  RTVY0001
     1  LSHFT,TFCFS)                                                    RTVY0002
      DIMENSICN  AWSBIT(99),BTRI(99),CTRI(99),SATRI(99)                 RTVY0003
      LOGICAL  LSHFT                                                    RTVY0004
      DO 100 KIA = 1,MXTRI                                              RTVY0005
      SATRI(KIA) = 0.0                                                  RTVY0006
  100 AWSBIT(KIA) = 0.0                                                 RTVY0007
      LSHFT = .FALSE.                                                   RTVY0008
      FMXTRI = MXTRI                                                    RTVY0009
      FNBTRI = NBTRI                                                    RTVY0010
      FNPTRI = NCTRI                                                    RTVY0011
      TFX = TFCFS                                                       RTVY0012
      TFMRT = 0.1*CHCAP                                                 RTVY0013
      IF(TFX .LT. TFMRT) TFX = TFMRT                                    RTVY0014
      IF(FNPTRI .EQ. FMXTRI .AND. TFX .EQ. TFMRT) RETURN                RTVY0015
      FNTRI = FNBTRI*(CHCAP/TFX)**EXQPV + 0.5                           RTVY0016
      IF(FNTRI .LT. 1.0) FNTRI = 1.01                                   RTVY0017
      NCTRI = FNTRI                                                     RTVY0018
      FNSTRI = NCTRI                                                    RTVY0019
      IF(FNSTRI .NE. FNPTRI) LSHFT = .TRUE.                             RTVY0020
      IF(.NOT. LSHFT) RETURN                                            RTVY0021
```

```
      IF(FNPTRI .GT. 98.5) GO TO 101                                    RTVY0022
      FCNTRI = ABS(FNSTRI - FNPTRI)                                     RTVY0023
      IF(FCNTRI .LE. 1.1) GO TO 101                                     RTVY0024
      IF(FNSTRI .GT. FNPTRI) FNSTRI = FNPTRI + 1.0                      RTVY0025
      IF(FNSTRI .LT. FNPTRI) FNSTRI = FNPTRI - 1.0                      RTVY0026
      NCTRI = FNSTRI                                                    RTVY0027
  101 KB1 = 0                                                           RTVY0028
      KB2 = 1                                                           RTVY0029
      KB3 = 0                                                           RTVY0030
  102 KB1 = KB1 + 1                                                     RTVY0031
      IF(KB1 .GT. NBTRI) GO TO 105                                      RTVY0032
      KB4 = 0                                                           RTVY0033
      WSBIT = BTRI(KB1)/FNSTRI                                          RTVY0034
  103 KB4 = KB4 + 1                                                     RTVY0035
      IF(KB4 .GT. NCTRI) GO TO 102                                      RTVY0036
      AWSBIT(KB2) = AWSBIT(KB2) + WSBIT                                 RTVY0037
      KB3 = KB3 + 1                                                     RTVY0038
      IF(KB3 .LT. NBTRI) GO TO 104                                      RTVY0039
      KB3 = 0                                                           RTVY0040
      KB2 = KB2 + 1                                                     RTVY0041
  104 GO TO 103                                                         RTVY0042
  105 IF(FNPTRI .GT. 98.5) GO TO 108                                    RTVY0043
      DO 107 KB6 = 1,NCTRI                                              RTVY0044
      DO 106 KB7 = 1,KB6                                                RTVY0045
  106 SATRI(KB6) = SATRI(KB6) + AWSBIT(KB7) - CTRI(KB7)                 RTVY0046
  107 CONTINUE                                                          RTVY0047
  108 DO 109 KB5 = 1,MXTRI                                              RTVY0048
  109 CTRI(KB5) = AWSBIT(KB5)                                           RTVY0049
      RETURN                                                            RTVY0050
      END                                                               RTVY0051
C
C
C
C
C     SUBROUTINE SNOMEL
      SUBROUTINE SNOMEL(BDDFSM,SPTWCC,SPM,ELDIF,DAY,SPBFLW,XDNFS,FFOR,  SNOW0001
```

```
     1 FFSI,MRNSM,DSMGH,SDEPTH,STMD,PXCSA,HOJR,SAX,SOFRF,OFRFIS,SOFRFI,SNOW0002
     2 AMFSIL,PRH,SPTW,TANSM,SPLW,SFMD,OFRF,WT4AM,WT4PM,ASM,ASMRG,      SNOW0003
     3 SASFX,SARAX,DMXT,DMNT,RICY,FIRR,TEH)                              SNOW0004
C  SNOWMELT COMPUTATION                                                 SNOW0005
      DIMENSION  DMNT(366),DMXT(366),FIRR(15),RICY(366)                 SNOW0006
      INTEGER  DAY,HOUR                                                 SNOW0007
      REAL  MHSM,MRNSM                                                  SNOW0008
      IF((DAY .NE. 274) .OR. (HOUR .NE. 1)) GO TO 100                   SNOW0009
      SPLW = 0.0                                                        SNOW0010
      XELR = 0.0                                                        SNOW0011
      SDSC = 0.0278                                                     SNOW0012
      FDSC = 0.0                                                        SNOW0013
      FTA = 0.0                                                         SNOW0014
      RICD = 0.0                                                        SNOW0015
      KRIA = 0                                                          SNOW0016
  100 CONTINUE                                                          SNOW0017
C  CALCULATION OF HOURLY AIR TEMPERATURE                                SNOW0018
C    DMXT CURRENT DAY, DMNT NEXT DAY                                    SNOW0019
      IF(HOUR .NE. 4) GO TO 101                                         SNOW0020
      FDSC = 0.0                                                        SNOW0021
      FTA = FDSC                                                        SNOW0022
      WT4PM = DMXT(DAY) - 4.0*ELDIF + (XELR/4.0)*0.7*ELDIF              SNOW0023
  101 IF(HOUR .EQ. 10) SDSC = -0.0278                                   SNOW0024
      IF(HOUR .EQ. 22) SDSC = 0.0278                                    SNOW0025
      IF(HOUR .NE. 16) GO TO 102                                        SNOW0026
      NDAY = DAY + 1                                                    SNOW0027
      IF(NDAY .EQ. 366) NDAY = 1                                        SNOW0028
      IF(NDAY .EQ. 60 .AND. DMXT(366) .NE. 0.0) NDAY = 366              SNOW0029
      IF(NDAY .EQ. 367) NDAY = 60                                       SNOW0030
      WT4AM = DMNT(NDAY) - (XELR/4.0)*3.3*ELDIF                         SNOW0031
  102 IF(PRH .LE. 0.0 .OR. XELR .GE. 4.0) GO TO 103                     SNOW0032
      WT4AM = WT4AM - 0.825*ELDIF                                       SNOW0033
      WT4PM = WT4PM + 0.175*ELDIF                                       SNOW0034
      XELR = XELR + 1.0                                                 SNOW0035
  103 IF(PRH .NE. 0.0 .OR. XELR .LE. 0.0) GO TO 104                     SNOW0036
      WT4AM = WT4AM + 0.825*ELDIF                                       SNOW0037
```

```
      WT4PM = WT4PM - 0.175*ELDIF
      XELR = XELR - 1.0
  104 TEH = WT4AM + FTA*(WT4PM - WT4AM)
      FOSC = FOSC + SDSC
      FTA = FTA + FOSC
      IF(PRH+SPTW .EQ. 0.0) GO TO 128
      IF(HOUR .NE. 24) GO TO 105
C  CALCULATION OF TIME AGING OF THE SNOWPACK
      SAX = SAX + 1.0
      IF(SAX .GT. 15.0) SAX = 15.0
  105 IF(TEH .GT. 32.0) GO TO 110
C  PRECIPITATICN IN FORM OF SNOW - CALCULATE INTERCEPTION DENSITY OF NEW
C    SNCW COMPACTION, AND SETTLING SNOW PACK AND THE EFFECT ON ALBEDO
      IF(PRH .LE. 0.0) GO TO 110
      PRH = SFM*PRH
      HSF = PRH
      ASM = ASM + HSF
      PRH = (1.0 - (FFSI*FFOR))*PRH
      HSFRG = PRH
      ASMRG = ASMRG + HSFRG
      FSIL = FFSI*FFOR*HSF
      AMFSIL = AMFSIL + FSIL
      IF(TEH .LE. 0.0) GO TO 106
      DNFS = XDNFS + ((0.01*TEH)**2)
      GC TO 107
  106 DNFS = XDNFS
  107 IF(SPTW .GT. 0.0 .AND. SDEPTH .GT. SPTW) SDEPTH = SDEPTH - ((PRH*
     1  SDEPTH/SPTW)*((0.10*SDEPTH)**0.25))
      SPTW = SPTW + PRH
      SDEPTH = SDEPTH + (PRH/DNFS)
      SASFX = SASFX + PRH
      IF(SASFX .GE. PXCSA) GO TO 108
      GO TO 109
  108 SAX = SAX - 1.0
      IF(SAX .LT. 0.0) SAX = 0.0
      SASFX = SASFX - PXCSA
```

```
  109 PRH = 0.0                                                         SNOW0074
  110 CONTINUE                                                          SNOW0075
      IF(SPTW .LE. 0.0) GO TO 127                                       SNOW0076
C  SEASONAL MELT FACTOR ADJUSTMENT                                      SNOW0077
C  PROGRAM MODIFICATION                                                 SNOW0078
      KAAO = KRIA                                                       SNOW0079
C  PROGRAM MODIFICATION                                                 SNOW0080
      RICD = RICY(DAY)                                                  SNOW0081
      IF(TEH .LE. 32.0) GO TO 111                                       SNOW0082
      GO TO 114                                                         SNOW0083
C  CALCULATION OF NEGATIVE MELT                                         SNOW0084
  111 IF(TANSM .LE. 11.5*MRNSM) GO TO 112                               SNOW0085
      IF(TANSM .LT. 1.0) TANSM = TANSM + ((5.0*MRNSM)**(1.3 + 2.0*      SNOW0086
     1  TANSM))                                                         SNOW0087
      GO TO 113                                                         SNOW0088
  112 TANSM = TANSM + MRNSM                                             SNOW0089
  113 IF(TANSM .GT. 0.08*SPTW) TANSM = 0.08*SPTW                        SNOW0090
      GO TO 127                                                         SNOW0091
C  EFFECT OF RAIN ON ALBEDO                                             SNOW0092
  114 SARAX = SARAX + PRH                                               SNOW0093
      IF(SARAX .LT. PXCSA/2.0) GO TO 115                                SNOW0094
      SAX = SAX + 1.0                                                   SNOW0095
      IF(SAX .GT. 15.0) SAX = 15.0                                      SNOW0096
      SASFX = 0.0                                                       SNOW0097
      SARAX = SARAX - (PXCSA/2.0)                                       SNOW0098
  115 IF(TEH .GT. 32.0) HSM = (TEH -32.0)*BDDFSM                        SNOW0099
      IF(TEH .LT. 32.0) HSM = 0.0                                       SNOW0100
      HSM = HSM*RICD                                                    SNOW0101
      KAA = 1.0 + SAX                                                   SNOW0102
      IF(SAX .LT. 15.0) HSM = HSM*(1.0 - ((1.0 - FFOR)*FIRR(KAA)))      SNOW0103
      IF(SAX .EQ. 15.0) HSM = HSM*(1.0 - ((1.0 - FFOR)*FIRR(15)))       SNOW0104
      IF(PRH .GT. 0.0) HSM = HSM + ((TEH - 32.0)*(PRH/144.0))           SNOW0105
      IF(STMD .GT. 0.3 .AND. SPTW .LT. SPTWCC) GO TO 116                SNOW0106
      GO TO 117                                                         SNOW0107
  116 MHSM = HSM                                                        SNOW0108
      HSM = (SPTW/SPTWCC)*HSM                                           SNOW0109
```

```
      IF(HSM .LT. 0.1*MHSM) HSM = 0.1*MHSM
  117 IF(HSM .LT. SPTW) GO TO 118
      HSM = SPTW
      SDEPTH = 0.0
      SPTW = C.0
      SPLW = C.0
      RICO = C.0
      TANSM = 0.0
      SAX = 15.0
      OFRF = SOFRF
      OFRFIS = SOFRFI
      GO TO 122
  118 SPTW = SPTW - HSM
      IF(SFMD .LE. 0.0) GO TO 122
      IF(SAX .GE. 15.0) GO TO 121
      IF(SAX .GE. 6.C) GO TO 119
      SDEPTH = SDEPTH - (HSM/(0.5*SFMD))
      GO TO 122
  119 IF(SAX .LE. 10.0) GO TO 120
      SDEPTH = SDEPTH - (HSM/(0.9*SFMD))
      GO TO 122
  120 SDEPTH = SDEPTH - (HSM/(0.7*SFMD))
      GO TO 122
  121 SDEPTH = SDEPTH - (HSM/SFMD)
  122 CONTINUE
      IF(SPTW .LT. 0.00001) SPTW = 0.0
C  CALCULATION OF LIQUID-WATER-HOLDING CAPACITY
      SPLWC = SPBFLW*SPTW
      IF(SFMD .GT. 0.6) SPLWC = SPBFLW*(3.0 - 3.33*SFMD)*SPTW
      IF(SPLWC .LT. 0.0) SPLWC = 0.0
C  ACCOUNTING OF MELT WATER AND RAIN
      IF((SPLW + HSM + PRH) .GT. (SPLWC + TANSM)) GO TO 123
      GO TO 124
  123 PRH = HSM + PRH + SPLW - SPLWC - TANSM
      SPLW = SPLWC
      SPTW = SPTW + TANSM
```

```
      TANSM = 0.0
      GO TO 127
  124 IF((HSM + PRH) .LE. TANSM) GO TO 126
  125 SPTW = SPTW + TANSM
      SPLW = SPLW + HSM + PRH - TANSM
      PRH = 0.0
      TANSM = 0.0
      GO TO 127
  126 TANSM = TANSM - HSM - PRH
      SPTW = SPTW + HSM + PRH
      PRH = 0.0
  127 CONTINUE
      HSM = 0.0
C  CALCULATION OF DENSITY AND ADJUSTMENT OF OVERLAND FLOW TIME
      IF(SDEPTH .LE. 0.0 .OR. SPTW .GE. SDEPTH) GO TO 128
      STMD = (SPTW + SPLW)/SDEPTH
      SFMD = SPTW/SDEPTH
      OFRF = 0.33*SOFRF
      IF(SPTW .LE. SPTWCC) OFRF = (1.0 - (SPTW/SPTWCC)*0.67)*SOFRF
  128 IF(SDEPTH .LE. 0.0) OFRF = SOFRF
      OFRFIS = SOFRFI*OFRF/SOFRF
C  CALCULATION OF GROUNDMELT
      IF( HOUR .NE. 12 .OR. SPTW .LE. 0.0) RETURN
      IF(SPTW .LE. DSMGH) GO TO 129
      PRH = PRH + DSMGH
      SPTW = SPTW - DSMGH
      IF(STMD .LT. 0.50 .AND. SDEPTH .GT. 2.0*DSMGH) SDEPTH = SDEPTH -
     1  2.0*DSMGH
      RETURN
  129 PRH = SPTW + PRH + SPLW
      TANSM = 0.0
      RICD = C.0
      SPLW = C.0
      SDEPTH = 0.0
      SPTW = C.0
      SAX = 15.0
```

```
      OFRF = SOFRF
      OFRFIS = SOFRFI
      RETURN
      END
```

APPENDIX B. CONTROL OPTIONS FOR PROGRAM LISTING ON APPENDIX A

CONTRCL OPTICNS FOR PROGRAM LISTING ON APPENDIX A

CPTICN	VALUE	DESCRIPTION
1	1	IF 15-MINUTE STORM DETAILS ARE REQUESTED.
2	1	IF RAIN IS NOT TO BE DIVIDED EQUALLY AMONG 15-MINUTE PERIODS.
3	1	IF EVAPORATION IS TO BE READ BY 10-DAY PERIODS. DAILY EVAPORATICN DATA ARE READ OTHERWISE.
4	1	IF A DAILY FOW ERROR TABLE IS REQUESTED. THIS OPTION CANNOT BE USED IF OPTION 9 IS NOT IN EFFECT.
5	1	IF THE TOP TWENTY HOURLY RAINFALLS AND OVERLAND FLOWS ARE REQUESTED.
6	1	IF DAILY SOIL MOISTURE STORAGE VALUES ARE REQUESTED.
7	1	IF SNOW IS TO BE INCLUDED IN THE ANALYSIS.
8	1	IF THE RAINFALL STORAGE GAGE SITE IS MCVED DURING THE WATER YEAR.
9	1	IF CAILY RECORDED STREAMFLOWS ARE TO BE READ.
10	1	IF NEXT YEAR OF DATA REQUIRES READING NEW PARAMETERS. THIS IS NORMALLY USED WHEN TWO WATERSHEDS ARE SYNTHESIZED IN THE SAME RUN.
11	1	IF STREAMFLOW DIVERSIONS ARE TO BE READ.
12	1	IF STREAM ROUTING IS TO BE DONE HCURLY. ROUTING IS DONE ON A 15-MINUTE INCREMENT OTHERWISE.

13	1	IF THE LENGTH OF THE TIME-AREA HISTOGRAM IS TO BE VARIED WITH FLCW.
14	1	IF THE RECORDED STREAMFLOWS ARE TO BE PRINTED.
15	1	IF THE SHEET EROSION MODEL IS TO BE INCLUDED IN THE ANALYSIS. THIS OPTION CANNOT BE USED IF OPTION 9 IS NOT IN EFFECT.
16	1	IF RECORDED SUSPENDED LOADS ARE TO BE READ FOR COMPARISON WITH SYNTHESIZED SUSPENDED LOADS. THIS OPTION CANNOT BE USED IF OPTIONS 9 AND 15 ARE NOT IN EFFECT.

APPENDIX C. SAMPLE INPUT DATA FOR PROGRAM LISTING ON APPENDIX A

INPUT DATA FOR WATERSHED AND SHEET EROSION MODELS
FOR
FOUR MILE CREEK NEAR TRAER, IOWA. 1970 WATER YEAR

```
 0  0  0  1  1  1  1  0  1  0  0  1  0  1  1  1
2
27
0.0094 0.0231 0.0288 0.0202 0.0239 0.0322 0.0283 0.0373 0.0370 0.0502 0.0587
0.0438 0.0373 0.0344 0.0442 0.0540 0.0460 0.0513 0.0536 0.0613 0.0434 0.0367
0.0300 0.0373 0.0352 0.0296 0.0128
0.76 0.75 0.74 0.73 0.72 0.71 0.70 0.69 0.68 0.66 0.64 0.62 0.60 0.58 0.56
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.001
0.100
0.100
0.100
0.100
0.100
0.005
0.005
0.005
0.005
```

```
0.005
0.005
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.0008 0.050C 0.250C 1.1500 0.0000 0.1000 0.0000 0.1000 0.1200 0.0000 0.0500
90.00  1.00  19.51 0.0250 0.0000
 0.150  1.00C  1.70C 12.000  0.300  0.000  0.100  2.000  8.000  0.000
 600.0  350.0 0.050C 0.0380 0.0150 0.3500 0.9800 0.9800 0.2000 1.0000 0.9730
0.2000 0.1400 8.599C 0.0250 0.0000 5.0     75
   2.0       1.50      1.330     0.0200   80.0     70 360
    20.0000    625.00      8330.0000       0.150   41600.0000      3.50
 61 400  3120.0
 DIGITAL SIMULATION OF STREAMFLOW, SHEET AND SCOUR EROSICN  -  TRIAL RUN 17
69 70
          FCLR MILE CREEK AREA NEAR TRAER, IOWA - WATERYEAR 1969-1970
315  91
0.05 0.05 0.C5 0.05 0.05 0.05 0.05 0.25 0.24 0.19 0.16 0.00 0.28 0.05 0.17  001
0.21 0.35 0.12 0.10 0.16 0.17 0.14 0.28 0.30 0.16 0.22 0.16 0.28 0.19 0.04  002
0.08 0.14 0.25 0.30 0.18 0.35 0.34 0.43 0.20 0.21 0.19 0.22 0.20 0.22 0.06  003
0.09 0.22 0.28 0.34 0.34 0.38 0.32 0.28 0.13 0.33 0.34 0.25 0.20 0.16 0.20  004
0.17 0.14 0.20 0.29 0.25 0.19 0.22 0.35 0.36 0.33 0.27 0.20 0.21 0.23 0.26  005
0.26 0.33 0.27 0.32 0.24 0.14 0.29 0.18 0.31 0.41 0.29 0.27 0.21 0.40 0.31  006
0.31 0.33 0.38 0.48 0.33 0.20 0.33 0.17 0.36 0.25 0.22 0.30 0.31 0.26 0.32  007
0.44 0.28 0.29 0.21 0.14 0.30 0.25 0.30 0.23 0.26 0.32 0.32 0.21 0.25 0.21  008
0.21 0.25 0.28 0.23 0.33 0.15 0.05 0.11 0.12 0.07 0.11 0.22 0.17 0.21 0.25  009
0.29 0.17 0.26 0.18 0.17 0.24 0.31 0.17 0.22 0.30 0.18 0.24 0.25 0.24 0.19  010
0.29 0.29 0.19 0.22 0.15 0.20 0.20 0.18 0.12 0.32 0.21 0.23 0.19 0.32 0.15  011
```

0.16	0.09	0.12	0.09	0.03	0.05	0.12	0.16	0.30	0.21	0.06	0.24	0.07	0.20	0.17	012
0.09	0.17	0.12	0.17	0.13	0.23	0.09	0.13	0.06	0.15	0.11	0.12	0.07	0.13	0.28	013
0.07	0.04	0.C4	0.03	0.13	0.06	0.10	0.03	0.15	0.09	0.15	0.02	0.04	0.06	0.05	014
0.03	0.12	0.06	0.02	0.03	0.07	0.04	0.04	0.03	0.03	0.05	0.06	0.04	0.09	0.03	015
1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.4	1.4	1.5	1.5	10 1			
1.6	1.6	1.6	1.5	1.4	1.5	1.5	1.5	1.6	1.6	1.6	1.6	10 2			
1.6	1.6	1.6	1.6	1.7	1.8	2.0	2.2	2.6	3.2	2.7	2.5	10 3			
2.4	2.3	2.6	5.6	4.5	3.6	3.1	2.8	2.5	2.3	2.2	2.3	10 4			
58.0	50.0	13.0	30.0	140.0	180.0	120.0	90.0	35.0	25.0	17.0	12.0	10 5			
215.0	208.0	28.0	17.0	14.0	12.0	10.0	9.0	8.6	8.2	7.8	7.6	10 6			
7.2	6.8	6.7	6.6	6.5	6.7	6.8	7.3	9.2	9.1	8.1	12.0	10 7			
18.0	13.0	10.0	11.0	9.9	9.6	9.4	9.0	8.3	7.9	8.0	7.8	10 8			
7.5	7.5	7.1	6.9	6.6	6.6	7.3	6.7	6.7	6.6	6.2	6.1	10 9			
7.4	10.0	8.9	8.3	7.1	6.9	6.5	6.3	6.1	5.8	5.6	5.7	10 10			
5.8	5.2	5.2	5.1	4.9	4.7	4.7	4.5	4.5	4.5	4.4	4.7	10 11			
11.0	102.0	36.0	24.0	19.0	16.0	14.0	12.0	11.0	10.0	72.0	41.0	10 12			
19.0	14.0	13.0	12.0	11.0	11.0	10.0	9.7	10.0	9.0	8.4	8.2	10 13			
7.5	7.1	6.5	6.3	6.1	5.8	5.8	5.5	5.3	5.1	5.0	4.7	10 14			
4.5	4.2	5.5	11.0	7.0	5.9	5.3	4.7	4.6	4.1	3.8	3.4	10 15			
3.1	2.9	2.8	3.0	2.6	2.4	2.3	2.4	2.2	1.9	2.0	1.4	10 16			
1.5	1.5	1.8	1.7	1.2	1.4	3.0	1.9	1.6	1.4	1.2	1.1	10 17			
1.0	0.9	0.8	1.2	1.0	1.2	1.0	0.8	0.7	0.9	0.4	0.8	10 18			
21.0	8.1	4.5	3.8	3.4	2.7	2.3	2.0	1.8	1.5	1.3	1.2	10 19			
1.1	10.0	5.0	3.0	2.4	2.2	1.9	1.7	1.5	1.5	1.4	1.1	10 20			
1.0	0.9	0.9	1.1	0.9	1.1	1.1	0.9	1.0	0.9	0.8	1.4	10 21			
3.2	1.2	0.9	0.8	1.9	9.5	6.5	4.3	3.7	3.1	2.6	2.5	10 22			
2.2	2.6	18.0	13.0	22.0	11.0	8.6	7.2	6.0	2.5	2.7	2.7	10 23			
2.5	2.5	2.7	2.8	2.7	2.5	2.4	2.6	3.1	6.5	4.2	3.8	10 24			
4.2	3.7	3.5	5.5	5.6	5.2	4.5	4.2	4.2	3.9	3.6	3.6	10 25			
3.6	3.6	4.2	8.8	7.0	5.8	5.2	5.2	4.7	4.7	4.6	4.6	10 26			
4.5	4.5	4.5	4.2	3.9	3.6	3.9	3.9	3.9	3.6	3.2	3.9	10 27			
3.7	3.9	3.7	3.6	3.6	3.5	3.5	3.2	3.2	3.6	3.4	2.8	10 28			
2.6	2.4	2.5	2.6	2.3	2.8	2.7	2.5	2.3	2.4	2.5	2.4	10 29			
2.3	2.2	2.2	2.2	2.1	2.1	2.0	1.9	1.9	1.8	1.8	1.7	10 30			
1.7	1.7	1.6	1.6	1.6	10 31										
0.32	0.31	0.31	0.30	0.31	0.31	0.29	0.27								

0.30	0.31	0.34	0.35	0.38	0.39	0.40	0.39
0.37	0.39	0.38	0.38	0.40	0.39	0.38	0.38
0.35	0.35	0.33	0.35	0.39	0.41	0.46	0.50
0.63	0.82	0.69	0.64	0.62	0.59	0.53	0.82
0.67	0.53	0.50	0.45	0.43	0.40	0.42	0.56
16.00	12.00	2.10	3.80	76.00	122.00	39.00	27.00
9.50	6.10	3.20	1.60	435.00	1240.00	36.00	9.20
5.70	4.20	2.70	1.80	2.30	2.00	2.10	2.90
3.30	3.70	3.60	3.20	2.80	2.50	2.20	2.20
3.00	2.90	2.60	4.50	12.00	6.30	6.40	4.60
2.70	2.10	1.90	1.70	1.50	1.30	1.20	1.10
1.00	1.00	0.96	0.88	0.84	0.84	0.89	0.81
0.78	0.77	0.67	0.66	0.74	1.60	1.30	1.20
0.96	0.93	0.88	0.83	0.86	0.78	0.60	0.54
0.47	0.32	0.35	0.34	0.33	0.29	0.29	0.28
0.36	0.46	0.42	0.63	22.00	767.00	46.00	21.00
11.00	8.40	6.40	4.90	3.70	2.70	630.00	248.00
47.00	19.00	7.20	3.60	2.20	1.80	1.40	1.30
1.40	1.10	1.00	1.00	0.81	0.77	0.70	0.60
0.58	0.55	0.47	0.45	0.43	0.34	0.34	0.32
0.30	0.28	4.50	28.00	2.50	1.30	1.00	0.70
0.56	0.46	0.46	0.46	0.46	0.49	0.48	0.51
0.45	0.40	0.37	0.36	0.31	0.26	0.26	0.17
0.18	0.22	0.44	0.39	0.26	0.28	1.20	0.54
0.35	0.14	0.13	0.12	0.10	0.10	0.09	0.39
0.30	0.32	0.24	0.18	0.15	0.23	0.11	0.21
88.00	3.90	0.80	0.65	0.55	0.42	0.34	0.28
0.23	0.18	0.15	0.12	0.10	8.10	1.50	0.47
0.34	0.27	0.21	0.16	0.12	0.16	0.38	0.28
0.24	0.21	0.21	0.25	0.21	0.30	0.29	0.22
0.24	0.21	0.17	0.42	1.70	0.29	0.19	0.16
1.30	14.00	3.90	1.90	1.10	0.52	0.42	0.39
0.88	1.30	44.00	24.00	28.00	4.40	2.00	1.50
0.97	0.84	0.90	0.90	0.84	0.84	0.90	0.93
0.90	0.83	0.78	0.81	1.30	2.80	1.60	1.20
1.30	1.10	1.10	1.70	1.70	1.60	1.40	1.30

```
     1.30      1.20      1.40      1.60      1.60      1.50      1.60      3.30
     2.50      1.90      1.40      1.20      0.90      0.89      0.84      0.82
     0.78      0.75      0.73      0.66      0.58      0.95      1.00      0.99
     0.97      0.87      0.74      0.86      0.80      0.83      0.76      0.70
     0.66      0.66      0.66      0.61      0.60      0.68      0.69      0.69
     0.60      0.58      0.65      0.63      0.53      0.62      0.58      0.51
     0.46      0.49      0.53      0.52      0.50      0.48      0.50      0.52
     0.50      0.49      0.46      0.44      0.43      0.41      0.41      0.38
     0.38      0.38      0.35      0.35      0.34         .         .         .
17.8 18.0 16.6 17.9 23.0 24.6 22.8 22.3 22.4  7.5  7.5 20.8 20.
 5.7  4.3 11.8 11.4 15.9 25.7 24.7 25.0  8.0 22.2 21.2  5.1 12.8
16.7 13.9 24.7 23.4 25.9 25.4 27.9 27.8 26.3  1.0 24.8 20.4  7.6
 8.9 17.4  8.2 12.4 22.8  9.0 20.3 27.2 28.8 11.7 36.2 31.6 32.9
33.3 35.8 32.3 37.1 23.9 33.1 13.0  6.3  2.2  6.3 39.0 35.1 39.4
34.6 36.9  9.4 38.7 36.1 41.3 37.9 36.9 45.8 47.2 37.3 26.8  4.6
40.8 47.3 31.0 14.7 35.8  4.7 24.1 25.7 47.7 34.6 38.1 37.8  8.8
40.3 27.5 52.1 28.1 50.5 50.8 49.1 51.2 44.2 37.2 13.1  5.5 34.5
11.5 53.7 55.3  4.5  4.1 25.6 55.0 41.8 51.9 54.5 55.2 51.6 52.1
54.0 32.1 12.5    .    .    .    .    .    .    .    .    .    .
 4.0  5.1  3.6 21.3 22.9 25.1 24.5 10.7 16.5 12.6 18.2 10.5  9.5
15.7 23.2  8.4  1.7 16.2 20.6 11.4 20.2 10.9 17.6 19.3 21.1 18.6
 6.6 18.5 20.4 19.0 18.8 17.4 19.4 19.5  4.2  1.8  8.3 19.3  9.2
00.0 21.8 16.1 17.9  8.3 17.1  8.3  3.4 13.2 13.6  7.0  6.2  5.9
17.6  6.7 17.6 21.8  4.8  7.8  9.9 12.1 10.2    .    .    .    .
29.0 24.0 17.0 11.0 18.0  2.0  0.0 -4.0 -2.0  6.0 22.0 28.0 18.0 17.0 25.0
34.0 12.0  1.0 -9.0 -3.0 -8.0  8.0 18.0 20.0 38.0 33.0 34.0 38.0 41.0 20.0
34.0 37.0 34.0 -4.0 17.0 35.0 35.0 32.0 36.0 31.0 28.0 30.0 30.0 25.0 11.0
17.0 21.0 36.0 48.0 30.0 20.0 28.0 44.0 38.0 46.0 41.0 24.0 43.0 32.0 34.0
34.0 52.0 60.0 41.0 50.0 45.0 44.0 42.0 28.0 37.0 37.0 34.0 27.0 34.0 34.0
40.0 44.0 47.0 34.0 39.0 43.0 50.0 35.0 46.0 35.0 30.0 29.0 29.0 34.0 42.0
42.0 37.0 46.0 39.0 48.0 59.0 54.0 74.0 59.0 60.0 61.0 60.0 60.0 42.0 60.0
53.0 64.0 56.0 47.0 48.0 45.0 58.0 78.0 63.0 71.0 78.0 81.0 85.0 89.0 84.0
48.0 41.0 41.0 40.0 52.0 61.0 66.0 65.0 59.0 63.0 62.0 59.0 49.0 28.0 27.0
43.0 53.0 56.0 29.0 37.0 23.0 41.0 47.0 42.0 55.0 49.0 50.0 29.0 43.0 36.0
54.0 49.0 46.0 35.0 34.0 31.0 31.0 31.0 21.0 32.0 19.0 22.0 29.0 31.0 27.0
20.0 26.0 32.0 31.0 24.0 27.0 28.0 22.0 23.0 24.0 28.0 15.0 25.0 28.0 22.0
```

24.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
11.0	1.0	5.0	-6.0	-12.0	-18.0	-15.0	-18.0	-17.0	-14.0	3.0	-1.0	-9.0	-9.0	16.0
12.0	-3.0	-20.0	-22.0	-22.0	-26.0	-26.0	0.0	0.0	19.0	22.0	18.0	17.0	14.0	8.0
8.0	20.0	-9.0	-14.0	-14.0	10.0	11.0	23.0	25.0	22.0	20.0	23.0	5.0	-1.0	-1.0
2.0	2.0	7.0	27.0	-3.0	-2.0	-1.0	24.0	20.0	23.0	7.0	7.0	17.0	18.0	19.0
33.0	35.0	13.0	24.0	27.0	28.0	27.0	22.0	21.0	21.0	19.0	14.0	16.0	14.0	14.0
18.0	24.0	28.0	31.0	20.0	21.0	27.0	22.0	29.0	23.0	15.0	4.0	15.0	23.0	24.0
26.0	21.0	23.0	26.0	31.0	34.0	31.0	43.0	31.0	24.0	26.0	37.0	39.0	36.0	41.0
34.0	34.0	38.0	40.0	36.0	34.0	33.0	32.0	36.0	44.0	50.0	57.0	60.0	61.0	51.0
37.0	37.0	37.0	36.0	29.0	32.0	34.0	34.0	35.0	40.0	35.0	24.0	26.0	12.0	12.0
20.0	21.0	26.0	13.0	10.0	11.0	18.0	25.0	26.0	28.0	18.0	25.0	12.0	20.0	20.0
27.0	26.0	26.0	10.0	10.0	26.0	28.0	17.0	12.0	16.0	5.0	6.0	21.0	17.0	4.0
-1.0	5.0	26.0	14.0	1.0	5.0	6.0	10.0	-5.0	12.0	4.0	-5.0	6.0	17.0	10.0
13.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

00

69	10	1	2				0.01	0.02	0.01	0.09	0.03				
69	10	5	2							0.03					0.01
69	10	6	1	0.05	0.05										
69	10	10	2								0.01	0.01	0.03		
69	10	11	1	0.04	0.06										
69	10	12	1							0.05	0.10	0.10	0.02	0.03	0.03
69	10	12	2	0.04	0.03	0.05	0.05	0.03	0.02	0.01	0.03	0.01	0.02	0.07	0.03
69	10	13	1	0.18	0.03										
69	10	15	2									0.01	0.03	0.01	0.04
69	10	16	1	0.05	0.01										
69	10	19	1	0.03	0.07	0.21	0.09	0.03	0.02	0.05	0.14				
69	10	19	2						0.01					0.04	
69	10	30	1									0.01	0.03	0.08	0.06
69	10	30	2	0.08	0.06	0.03	0.01	0.01	0.03	0.06	0.02	0.06	0.11	0.12	0.03
69	10	31	1	0.02	0.04	0.01			0.01						
69	11	3	1									0.01	0.01	0.01	0.01
69	11	3	2		0.01		0.01								
69	11	17	2						0.06	0.01					
69	12	6	1												0.02
69	12	6	2	0.02			0.03	0.02		0.04	0.01		0.04	0.01	0.05
69	12	7	1	0.05	0.04	0.03	0.03	0.08	0.07	0.06	0.04	0.07	0.04	0.03	0.01

69	12	7	2	0.02	0.01										
69	12	9	1											0.01	0.01
69	12	9	2	0.01							0.01				0.01
69	12	20	2											0.01	0.01
69	12	21	1	0.04	0.04	0.04	0.02								
69	12	22	2	0.02					0.01		0.01	0.01	0.01	0.06	0.14
69	12	23	1	0.11	0.06	0.04		0.04	0.01	0.04	0.01	0.03			
69	12	24	1											0.02	0.05
69	12	24	2	0.02	0.03	0.01									
69	12	27	2			0.01	0.08	0.03	0.01	0.01					0.01
69	12	28	1	0.01		0.03	0.01	0.01							
70	1	1	1			0.01			0.01	0.01				0.02	0.01
70	1	17	1								0.02	0.02	0.01		
70	1	17	2	0.01											
70	1	18	2										0.01		
70	1	19	1		0.01										
70	1	22	2	0.03	0.04	0.01	0.01								
70	1	25	2								0.01	0.02	0.01	0.01	
70	2	4	1						0.01	0.01	0.03			0.01	
70	2	4	2	0.01											
70	2	8	2		0.03	0.01	0.01	0.01	0.01	0.01	0.02				
70	2	28	2							0.01	0.01	0.01	0.01	0.01	0.01
70	3	1	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
70	3	2	1		0.01	0.02	0.01					0.34	0.26	0.21	0.29
70	3	2	2	0.18	0.11	0.01	0.06	0.04	0.03	0.02		0.01	0.16		
70	3	3	1	0.03		0.02	0.04		0.02	0.03					
70	3	9	2					0.02	0.03	0.04	0.02	0.04	0.02	0.03	0.04
70	3	10	1	0.01	0.02	0.02	0.03								
70	3	19	1										0.01	0.07	0.07
70	3	19	2	0.06	0.10	0.10	0.09	0.05	0.03	0.02	0.01				
70	3	20	1			0.02	0.01								
70	3	24	2										0.03	0.03	0.03
70	3	25	1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05			
70	3	25	2	0.01	0.02	0.01			0.01	0.03	0.01				0.01
70	3	26	1		0.02	0.05	0.02	0.01							
70	4	12	1			0.10	0.02								

70	4	12	2						0.07	0.18	0.04	0.06			
70	4	13	1		0.01	0.01	0.03								
70	4	15	2		0.04	0.01		0.02	0.01	0.01		0.01			
70	4	19	1												0.01
70	4	19	2	0.01	0.02	0.05	0.27	0.18	0.02	0.09	0.03				
70	4	22	1						0.05	0.03	0.02			0.02	0.01
70	4	22	2	0.02											
70	4	29	2					0.27	0.41						
70	4	30	2		0.02	0.03			0.01	0.02		0.02		0.01	0.05
70	5	1	1	0.01				0.08							
70	5	4	1	0.04											
70	5	9	2			0.04	0.02		0.03						
70	5	11	2							0.26					
70	5	12	1	0.30	0.08	0.06									
70	5	12	2											0.33	0.14
70	5	13	1	0.27	0.31	0.10									
70	5	13	2									0.04	0.32	0.28	0.12
70	5	14	1	0.54	0.26	0.10				0.12	0.07	0.04		0.01	0.01
70	5	14	2				0.01		0.01						
70	5	22	2									0.03	0.07	0.10	
70	5	23	1						0.72	0.01					
70	5	24	1						0.26						
70	5	24	2						0.26						
70	5	27	2	0.04	0.02			0.02	0.01						
70	5	29	1									0.02		0.02	
70	5	29	2		0.01			0.08	0.01						
70	6	1	2				0.04	0.04	0.02	0.01	0.03	0.01		0.05	0.03
70	6	2	1	0.01	0.01										
70	6	12	1							0.01	0.05	0.04		0.02	0.18
70	6	12	2	0.02	0.01				0.01						
70	6	14	2	0.94	0.01										
70	6	16	1			0.27	0.02	0.01	0.10		0.03				
70	6	17	2								0.27				
70	6	20	1		0.03	0.10	0.13		0.01	0.03					0.30
70	6	20	2		0.01	0.03		0.06	0.16	0.02					
70	6	25	2												0.02

70	7	3	1	0.35	0.05										
70	7	6	2					0.11	0.01						
70	7	13	2	0.01		0.02					0.20	0.01		0.21	0.01
70	7	14	1	0.02		0.02				0.01		0.01			
70	7	14	2								0.37	0.01	0.01		
70	7	15	1	0.01											
70	7	17	1				0.13	0.12	0.15	0.03					
70	7	18	1					0.24	0.11	0.18	0.40	0.12	0.01	0.02	0.01
70	7	18	2	0.01											
70	7	27	1			0.01	0.07	0.05	0.05	0.06	0.04				
70	7	28	2				0.17	0.03		0.01					
70	7	29	1	0.02	0.11			0.10		0.01		0.02		0.01	
70	7	30	1	0.01	0.05						0.01				
70	8	4	1			0.01	0.01	0.01	0.05	0.07	0.14	0.10			
70	8	4	2	0.01					0.08	0.01	0.02	0.01	0.08	0.24	0.02
70	8	5	1	0.18	0.49	0.36	0.14	0.07	0.17	0.12	0.01				
70	8	7	2			0.03			0.01						
70	8	8	1								0.01			0.01	
70	8	17	2		0.01	0.01	0.01								0.10
70	8	18	1	0.21	0.02	0.19	0.38		0.01		0.01				
70	8	21	2												0.03
70	8	22	1							0.01					
70	9	2	2									0.08	0.01	0.01	
70	9	3	1							0.02			0.16		
70	9	6	1								0.11				
70	9	9	2			0.02	0.37	0.37	0.11	0.02					
70	9	12	1									0.06	0.02		
70	9	13	1											0.01	0.01
70	9	13	2	0.04	0.03	0.01	0.01		0.01	0.01					0.02
70	9	14	1	0.01		0.01	0.06	0.21	0.07	0.05	0.02	0.02	0.01		
70	9	14	2	0.01	0.07	0.10	0.04	0.01	0.01			0.01	0.08	0.11	0.44
70	9	15	1	0.40	0.34	0.09				0.04					
70	9	16	2						0.01			0.03	0.02	0.05	0.03
70	9	17	1	0.01	0.03					0.01	0.02				
70	9	21	1						0.02	0.01	0.01	0.01			
70	9	23	1											0.04	0.14

70	9	23	2	0.16	0.10	0.05	0.01	0.02		0.01					0.01
70	9	24	1	0.33											
70	9	25	1										0.01	0.01	0.01
70	9	25	2		0.20	0.51	0.10	0.01	0.04					0.01	
98	9	30	1												

APPENDIX D. STREAMFLOW SIMULATION RESULTS FOR FOUR MILE CREEK WATERSHED NEAR TRAER, IOWA

Table D-1. Daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year

Date	Mean daily streamflow in cubic feet per second							
	October		November		December		January	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	2.5	2.9	7.0	6.6	3.4	2.8	1.5	1.2
2	2.7	3.4	5.8	5.3	2.8	2.7	1.5	1.2
3	2.7	2.7	5.2	5.1	2.6	2.7	1.5	1.2
4	2.5	2.6	5.2	5.1	2.4	2.6	1.5	1.1
5	2.5	2.5	4.7	5.0	2.5	2.5	1.5	1.1
6	2.7	2.4	4.7	4.9	2.6	2.5	1.5	1.1
7	2.8	2.3	4.6	4.8	2.3	2.4	1.4	1.0
8	2.7	2.3	4.6	4.7	2.8	2.3	1.3	1.0
9	2.5	2.2	4.5	4.6	2.7	2.3	1.4	1.0
10	2.4	2.1	4.5	4.5	2.5	2.2	1.4	1.0
11	2.6	2.6	4.5	4.3	2.3	2.1	1.5	0.9
12	3.1	4.8	4.2	4.2	2.4	2.1	1.5	0.9
13	6.5	7.4	3.9	4.1	2.5	2.0	1.6	0.9
14	4.2	3.1	3.6	4.0	2.4	2.0	1.6	0.9
15	3.8	2.2	3.9	3.9	2.3	1.9	1.6	0.8
16	4.2	3.1	3.9	3.8	2.2	1.9	1.5	0.8
17	3.7	2.4	3.9	3.7	2.2	1.8	1.4	0.8
18	3.5	2.2	3.6	3.7	2.2	1.8	1.5	0.8
19	5.5	9.6	3.2	3.7	2.1	1.7	1.5	0.8
20	5.6	5.6	3.9	3.7	2.1	1.7	1.5	0.7
21	5.2	3.9	3.7	3.6	2.0	1.6	1.6	0.7
22	4.5	3.5	3.9	3.5	1.9	1.6	1.6	0.7
23	4.2	3.4	3.7	3.5	1.9	1.6	1.6	0.7
24	4.2	3.4	3.6	3.4	1.8	1.5	1.6	0.7
25	3.9	3.3	3.6	3.3	1.8	1.5	1.6	0.6
26	3.6	3.2	3.5	3.2	1.7	1.4	1.6	0.6
27	3.6	3.1	3.5	3.1	1.7	1.4	1.6	0.6
28	3.6	3.0	3.2	3.0	1.7	1.4	1.6	0.6
29	3.6	2.9	3.2	2.9	1.6	1.3	1.7	2.1
30	4.2	5.6	3.6	2.9	1.6	1.3	1.8	6.3
31	8.8	13.7			1.6	1.3	2.0	1.7
Total	118.1	117.3	124.9	120.0	68.6	59.9	48.0	34.5

Table D-1 (Continued)

Date	Mean daily streamflow in cubic feet per second							
	February		March		April		May	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	2.2	0.9	12.0	4.2	9.4	5.7	5.8	6.4
2	2.6	0.9	215.0	346.5	9.0	5.8	5.2	4.2
3	3.2	0.9	208.0	326.3	8.3	5.6	5.2	3.6
4	2.7	0.9	28.0	56.9	7.9	5.4	5.1	3.5
5	2.5	0.9	17.0	14.0	8.0	5.3	4.9	3.3
6	2.4	0.9	14.0	7.7	7.8	5.2	4.7	3.2
7	2.3	0.8	12.0	6.5	7.5	5.0	4.7	3.1
8	2.6	0.8	10.0	6.2	7.5	4.9	4.5	3.0
9	5.6	0.8	9.0	6.0	7.1	4.7	4.5	2.9
10	4.5	0.8	8.6	6.4	6.9	4.5	4.5	2.8
11	3.6	0.8	8.2	5.8	6.6	4.4	4.4	3.1
12	3.1	0.8	7.8	5.6	6.6	5.3	4.7	8.9
13	2.8	0.8	7.6	5.5	7.3	8.0	11.0	33.6
14	2.5	0.8	7.2	5.3	6.7	4.9	102.0	247.3
15	2.3	0.8	6.8	5.2	6.7	4.3	36.0	60.2
16	2.2	0.7	6.7	5.0	6.6	4.1	24.0	18.3
17	2.3	0.7	6.6	4.9	6.2	4.0	19.0	12.1
18	58.0	22.0	6.5	4.7	6.1	3.8	16.0	10.9
19	50.0	46.4	6.7	8.6	7.4	6.2	14.0	10.4
20	13.0	8.0	6.8	10.8	10.0	9.2	12.0	10.0
21	30.0	2.4	7.3	6.7	8.9	4.9	11.0	9.7
22	140.0	118.3	9.2	5.9	8.3	4.8	10.0	9.3
23	180.0	273.3	9.1	5.7	7.1	4.3	72.0	60.1
24	120.0	212.6	8.1	5.5	6.9	3.9	41.0	36.3
25	90.0	114.6	12.0	6.3	6.5	3.7	19.0	23.4
26	35.0	20.2	18.0	7.4	6.3	3.6	14.0	13.0
27	25.0	6.6	13.0	6.8	6.1	3.5	13.0	11.2
28	17.0	4.6	10.0	6.2	5.8	3.4	12.0	10.5
29			11.0	6.1	5.6	5.4	11.0	10.3
30			9.9	6.0	5.7	9.3	11.0	10.0
31			9.6	5.9			10.0	9.7
Total	807.4	843.0	721.7	910.5	216.8	152.7	516.2	654.4

Table D-1 (Continued)

Date	Mean daily streamflow in cubic feet per second							
	June		July		August		September	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	9.7	9.5	2.9	5.3	0.7	1.5	1.1	0.9
2	10.0	9.7	2.8	5.0	0.9	1.4	0.9	0.8
3	9.0	9.3	3.0	8.2	0.4	1.4	1.1	1.5
4	8.4	8.9	2.6	5.3	0.8	4.1	0.9	1.2
5	8.2	8.6	2.4	4.4	21.0	22.4		0.8
6	7.5	8.3	2.3	4.2	8.1	7.1	1.0	0.7
7	7.1	8.0	2.4	4.0	4.5	2.8	0.9	0.7
8	6.5	7.7	2.2	3.8	3.8	2.1	0.8	0.7
9	6.3	7.4	1.9	3.6	3.4	1.9	1.4	3.8
10	6.1	7.1	2.0	3.5	2.7	1.8	3.2	7.1
11	5.8	6.8	1.4	3.3	2.3	1.8	1.2	1.6
12	5.8	8.0	1.5	3.2	2.0	1.7	0.9	1.0
13	5.5	7.5	1.5	3.2	1.8	1.6	0.8	1.0
14	5.3	13.2	1.8	6.9	1.5	1.5	1.9	5.9
15	5.1	12.9	1.7	6.6	1.3	1.5	9.5	20.7
16	5.0	11.1	1.2	3.3	1.2	1.4	6.5	6.2
17	4.7	8.3	1.4	5.9	1.1	1.4	4.3	4.8
18	4.5	9.4	3.0	2.5	10.0	9.9	3.7	3.3
19	4.2	7.2	1.9	6.5	5.0	3.7	3.1	2.9
20	5.5	12.2	1.6	3.1	3.0	1.8	2.6	2.8
21	11.0	12.2	1.4	2.5	2.4	1.4	2.5	2.7
22	7.0	8.3	1.2	2.3	2.2	1.3	2.2	2.6
23	5.9	7.4	1.1	2.2	1.9	1.3	2.6	5.8
24	5.3	7.1	1.0	2.1	1.7	1.2	18.0	11.8
25	4.7	6.8	0.9	2.0	1.5	1.2	13.0	14.9
26	4.6	6.5	0.8	1.9	1.5	1.1	22.0	18.8
27	4.1	6.3	1.2	3.4	1.4	1.1	11.0	9.7
28	3.8	6.0	1.0	3.0	1.1	1.0	8.6	8.3
29	3.4	5.7	1.2	4.4	1.0	1.0	7.2	8.0
30	3.1	5.5	1.0	2.3	0.9	0.9	6.0	7.8
31			0.8	1.6	0.9	0.9		
Total	183.1	252.8	53.1	129.6	92.0	85.1	140.0	159.1

Table D-2. Mean daily recorded and simulated streamflows for the Four Mile Creek watershed near Traer, Iowa for the 1971 water year

Date	Mean daily streamflow in cubic feet per second							
	October		November		December		January	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	5.5	7.7	9.5	18.6	10.0	14.6	6.5	7.3
2	5.0	7.6	9.5	18.3	9.3	14.2	5.9	7.2
3	4.5	7.4	9.2	17.9	9.3	13.8	4.3	7.1
4	4.2	7.1	8.9	17.6	8.5	13.4	3.0	6.9
5	4.2	6.9	8.8	17.2	7.9	13.0	4.2	6.7
6	3.9	6.7	16.8	9.5	12.7	5.0	6.5	
7	3.8	6.5	8.2	16.4	8.8	12.4	5.4	6.4
8	5.6	27.3	8.2	15.9	8.7	12.0	5.5	6.2
9	119.0	130.3	15.0	26.4	8.1	11.7	5.6	6.0
10	44.0	39.5	15.0	21.3	8.1	12.8	5.6	5.9
11	28.0	22.2	13.0	17.8	8.7	14.4	5.7	5.7
12	24.0	19.4	12.0	16.9	8.1	12.6	5.7	5.6
13	21.0	18.6	11.0	16.5	8.3	12.0	5.6	5.4
14	18.0	18.1	11.0	16.4	8.5	11.7	5.6	5.3
15	16.0	17.6	10.0	16.5	8.3	11.4	5.5	5.2
16	15.0	17.1	10.0	16.3	8.0	11.2	5.5	5.0
17	14.0	16.6	9.7	16.0	7.3	10.9	5.4	4.9
18	13.0	16.1	9.3	15.7	7.5	10.6	5.3	4.8
19	12.0	15.6	10.0	18.6	6.8	10.3	5.3	4.7
20	12.0	15.2	16.0	32.8	7.1	10.1	5.2	4.5
21	11.0	14.7	14.0	20.9	7.2	9.8	5.2	4.4
22	12.0	31.5	13.0	18.6	7.3	9.6	5.1	4.3
23	12.0	23.5	14.0	17.9	6.3	9.3	5.1	4.2
24	12.0	26.2	13.0	17.4	6.4	9.1	5.0	4.1
25	12.0	20.6	12.0	17.0	6.6	8.8	5.3	4.0
26	11.0	19.2	10.0	16.6	6.4	8.6	4.9	3.9
27	11.0	19.4	10.0	16.2	6.2	8.4	4.8	3.8
28	11.0	21.4	9.8	15.8	6.1	8.2	4.8	3.7
29	10.0	19.5	10.0	15.4	6.2	8.0	4.9	3.6
30	10.0	19.2	10.0	15.0	6.6	7.7	4.6	3.5
31	9.7	18.9			6.5	7.5	4.2	3.4
Total	494.4	657.6	328.8	540.7	238.6	340.7	160.1	159.7

Table D-2 (Continued)

Date	Mean daily streamflow in cubic feet per second							
	February		March		April		May	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	4.1	3.3	110.0	18.1	12.0	15.7	7.0	7.9
2	3.9	3.2	80.0	8.8	11.0	15.2	6.5	6.7
3	4.0	3.1	58.0	7.4	10.0	14.8	6.3	6.4
4	4.1	3.1	56.0	7.1	9.9	14.4	6.5	6.2
5	3.3	3.0	60.0	15.8	9.7	13.9	6.3	6.0
6	4.5	2.9	25.0	60.8	9.6	13.5	6.1	5.8
7	3.9	2.8	18.0	15.5	9.4	13.0	5.9	5.7
8	3.7	2.8	10.0	8.6	8.7	12.6	5.8	5.5
9	3.6	2.7	11.0	7.5	8.6	12.2	5.6	5.3
10	3.6	2.6	20.0	7.3	9.4	11.8	5.5	5.1
11	3.4	2.6	120.0	7.2	9.0	13.3	5.5	5.0
12	3.3	2.5	230.0	100.3	9.1	12.2	5.3	4.8
13	3.2	2.4	384.0	368.7	8.6	11.0	5.3	4.6
14	3.3	2.4	306.0	444.8	8.1	10.5	5.1	4.5
15	3.3	2.3	58.0	313.6	8.0	10.2	4.9	4.3
16	3.4	2.2	24.0	135.1	9.1	10.8	4.9	4.1
17	4.4	19.3	26.0	33.2	9.8	12.1	5.4	5.0
18	50.0	144.8	43.0	21.1	9.1	9.7	38.0	12.5
19	150.0	184.7	29.0	36.3	8.7	10.5	32.0	17.4
20	120.0	187.7	23.0	24.3	8.3	9.7	17.0	6.9
21	94.0	33.2	29.0	21.5	8.7	10.2	13.0	5.2
22	70.0	10.3	25.0	20.7	7.9	8.7	12.0	4.8
23	58.0	7.0	20.0	20.2	7.5	8.2	12.0	7.8
24	48.0	6.3	15.0	19.8	7.1	7.9	72.0	49.4
25	40.0	11.5	13.0	19.4	6.8	7.7	27.0	16.8
26	90.0	44.1	12.0	18.9	6.6	7.4	20.0	8.8
27	200.0	25.7	21.0	18.4	9.0	13.6	17.0	7.4
28	160.0	79.1	22.0	17.8	8.2	8.7	14.0	7.0
29			15.0	17.3	7.5	7.3	13.0	6.8
30			16.0	16.7	7.3	7.2	12.0	6.5
31			17.0	16.2			12.0	17.6
Total	1143.7	797.6	1896.0	1848.8	262.7	334.0	408.9	267.7

Table D-2 (Continued)

Date	Mean daily streamflow in cubic feet per second							
	June		July		August		September	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	37.0	117.5	5.2	5.1	2.6	3.2	0.4	0.8
2	13.0	26.2	4.6	3.5	3.1	7.2	0.3	0.7
3	12.0	10.7	5.5	3.1	2.5	3.5	0.4	0.7
4	11.0	8.2	20.0	8.1	2.4	2.7	0.7	3.7
5	10.0	7.5	12.0	10.1	2.1	2.5	2.5	7.8
6	10.0	8.1	9.0	4.2	2.1	2.4	2.0	1.8
7	16.0	9.5	7.9	3.8	2.0	2.3	0.5	0.8
8	10.0	7.7	125.0	6.2	1.9	2.2	1.1	0.7
9	9.8	7.1	17.0	3.8	1.8	2.1	0.8	2.7
10	9.1	6.8	73.0	27.0	1.6	2.0	0.4	2.3
11	9.4	6.5	25.0	26.4	1.4	1.9	0.3	0.8
12	9.2	6.7	14.0	10.4	1.3	1.8	0.3	0.6
13	30.0	10.3	11.0	9.4	1.2	1.8	0.3	0.6
14	14.0	6.8	9.1	7.5	1.1	1.7	0.3	0.5
15	11.0	6.1	8.0	6.9	1.1	1.6	0.3	0.5
16	9.5	5.8	6.9	6.6	0.9	1.5	0.3	0.5
17	8.9	5.6	6.4	6.2	0.8	1.5	0.2	0.5
18	11.0	6.0	6.0	5.9	0.8	1.4	0.3	0.5
19	8.8	5.4	5.4	5.7	1.1	3.1	0.6	4.2
20	8.1	5.0	5.0	5.3	0.9	2.0	0.4	1.9
21	7.5	4.8	4.7	5.1	0.7	1.3	0.4	0.6
22	7.2	4.6	4.4	4.8	0.8	1.2	0.4	0.4
23	6.7	4.4	4.3	7.3	0.7	1.1	0.5	0.4
24	6.3	4.2	4.0	5.1	1.1	1.1	0.4	0.4
25	6.1	4.0	3.8	4.7	1.2	1.1	0.5	2.4
26	6.1	3.9	3.7	4.8	1.0	1.0	0.5	1.5
27	5.6	3.7	3.5	4.4	0.5	1.0	0.4	0.5
28	5.5	3.5	3.6	5.4	0.4	0.9	0.4	0.4
29	5.4	3.6	3.2	3.7	0.4	0.9	0.3	0.4
30	8.5	12.4	3.1	3.3	0.4	0.8	0.4	0.4
31			2.9	3.1	0.4	0.8		
Total	322.7	322.4	417.2	217.0	40.3	59.9	16.6	39.8

APPENDIX E. SEDIMENT SIMULATION RESULTS FOR FOUR MILE CREEK WATERSHED NEAR TRAER, IOWA

Table E-1. Daily recorded and simulated suspended sediment loads for the Four Mile Creek watershed near Traer, Iowa for the 1970 water year

Date	Daily suspended sediment load in tons							
	October		November		December		January	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	0.8	0.7	2.5	3.1	0.7	0.8	0.3	0.3
2	0.9	1.3	1.9	1.7	0.7	0.6	0.3	0.3
3	0.9	0.6	1.4	1.4	0.6	0.5	0.3	0.3
4	0.8	0.5	1.2	1.3	0.6	0.5	0.3	0.3
5	0.8	0.5	0.9	1.2	0.6	0.5	0.3	0.3
6	0.9	0.7	0.9	1.2	0.6	0.5	0.3	0.3
7	0.9	0.6	0.8	1.1	0.5	0.5	0.3	0.2
8	0.9	0.6	0.8	1.1	0.6	0.6	0.3	0.2
9	0.8	0.5	0.8	1.1	0.6	0.6	0.3	0.2
10	0.8	0.6	0.8	1.1	0.5	0.5	0.3	0.2
11	0.8	1.4	0.7	1.1	0.5	0.5	0.3	0.3
12	1.3	3.0	0.7	1.0	0.5	0.5	0.3	0.3
13	2.8	7.2	0.6	0.9	0.5	0.5	0.4	0.3
14	1.6	2.0	0.9	0.8	0.5	0.5	0.4	0.3
15	1.2	1.0	1.0	0.9	0.5	0.5	0.4	0.3
16	1.3	1.6	1.0	0.9	0.5	0.4	0.4	0.3
17	1.1	1.0	1.0	1.0	0.5	0.4	0.4	0.2
18	1.1	0.8	0.9	0.8	0.5	0.4	0.4	0.3
19	1.7	9.7	0.7	0.7	0.5	0.4	0.4	0.3
20	1.7	4.0	0.9	0.9	0.5	0.4	0.4	0.3
21	1.6	1.7	0.8	0.9	0.5	0.4	0.4	0.3
22	1.4	1.1	0.8	0.9	0.4	0.4	0.4	0.3
23	1.3	1.0	0.8	0.9	0.4	0.4	0.4	0.3
24	1.3	1.0	0.7	0.8	0.4	0.3	0.4	0.3
25	1.2	0.9	0.7	0.8	0.4	0.3	0.3	0.3
26	1.4	0.8	0.7	0.8	0.4	0.3	0.3	0.3
27	1.6	0.8	0.7	0.8	0.4	0.3	0.3	0.3
28	1.6	0.8	0.6	0.7	0.4	0.3	0.3	0.3
29	1.5	0.8	0.6	0.7	0.3	0.3	0.4	0.5
30	1.6	2.8	0.7	0.8	0.3	0.3	0.4	0.8
31	3.3	9.5			0.3	0.3	0.5	0.4
Total	41.07	59.80	27.29	31.20	15.31	13.70	11.01	9.70

Table E-1 (Continued)

Date	Daily suspend sediment load in tons							
	February		March		April		May	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	0.5	0.4	1.6	4.1	1.9	3.0	0.5	5.0
2	0.6	0.5	435.0	1465.0	1.7	2.8	0.3	2.0
3	0.8	0.7	1240.0	1221.5	1.5	2.5	0.3	1.4
4	0.7	0.6	36.0	166.9	1.3	2.3	0.3	1.3
5	0.6	0.5	9.2	28.7	1.2	2.4	0.3	1.2
6	0.6	0.5	5.7	8.2	1.1	2.3	0.3	1.2
7	0.6	0.5	4.2	4.5	1.0	2.2	0.3	1.2
8	0.5	0.5	2.7	3.2	1.0	2.2	0.3	1.1
9	0.8	1.5	1.8	2.9	1.0	2.0	0.4	1.2
10	0.7	1.1	2.3	3.1	0.9	2.0	0.5	1.1
11	0.5	0.8	2.0	2.6	0.8	1.8	0.4	2.2
12	0.5	0.7	2.1	2.3	0.8	3.4	0.6	15.0
13	0.4	0.6	2.9	2.2	0.9	6.2	22.0	59.2
14	0.4	0.5	3.3	2.1	0.8	2.5	767.0	898.4
15	0.4	0.5	3.7	1.9	0.8	2.0	46.0	189.7
16	0.4	0.4	3.6	1.9	0.8	1.9	21.0	35.0
17	0.6	0.5	3.2	1.8	0.7	1.7	11.0	11.1
18	16.0	33.8	2.8	1.8	0.7	1.7	8.4	6.4
19	12.0	28.3	2.5	4.9	0.7	6.3	6.4	5.0
20	2.1	4.7	2.2	5.7	1.6	11.4	4.9	4.1
21	3.8	13.8	2.2	2.7	1.3	3.9	3.7	3.6
22	76.0	111.8	3.0	2.9	1.2	2.9	2.7	3.3
23	122.0	158.4	2.9	2.8	1.0	2.2	630.0	235.8
24	39.0	93.4	2.6	2.4	0.9	2.0	248.0	103.6
25	27.0	63.2	4.5	4.6	0.9	1.8	47.0	33.5
26	9.5	17.5	12.0	7.7	0.8	1.7	19.0	8.7
27	6.1	10.9	6.3	4.8	0.9	1.7	7.2	5.1
28	3.2	6.5	6.4	3.2	0.8	1.6	3.6	4.1
29			4.6	3.6	0.6	7.5	2.2	3.8
30			2.7	3.2	0.5	18.3	1.8	3.7
31			2.1	3.0			1.4	3.2
Total	326.50	553.0	1816.10	2976.60	30.20	106.10	1857.84	1651.00

Table E-1 (Continued)

Date	Daily suspended sediment load in tons							
	June		July		August		September	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	1.3	3.4	0.5	0.6	0.1	0.1	0.3	0.2
2	1.4	3.7	0.5	0.6	0.2	0.1	0.2	0.2
3	1.1	2.8	0.5	10.9	0.1	0.0	0.3	2.3
4	1.0	2.5	0.4	2.7	0.2	3.3	0.3	1.2
5	1.0	2.5	0.4	0.7	88.0	55.6	0.2	0.2
6	0.8	2.2	0.4	0.8	3.9	13.8	0.2	0.5
7	0.8	2.0	0.4	0.5	0.8	2.7	0.2	0.1
8	0.7	1.8	0.3	0.4	0.6	1.0	0.2	0.1
9	0.6	1.7	0.3	0.4	0.5	0.8	0.4	9.9
10	0.6	1.7	0.3	0.4	0.4	0.6	1.7	19.1
11	0.5	1.6	0.2	0.2	0.3	0.5	0.3	2.8
12	0.5	4.2	0.2	0.3	0.3	0.4	0.2	0.7
13	0.4	3.2	0.2	1.1	0.2	0.3	0.2	0.3
14	0.4	43.5	0.4	9.5	0.2	0.3	1.3	6.3
15	0.3	40.4	0.4	12.3	0.1	0.2	14.0	48.8
16	0.3	13.8	0.3	2.0	0.1	0.2	3.9	11.2
17	0.3	4.6	0.3	4.8	0.1	0.2	1.9	3.0
18	0.3	7.2	1.2	22.2	8.1	22.7	1.1	1.2
19	0.3	1.9	0.5	9.0	1.5	6.4	0.5	0.7
20	4.5	10.0	0.3	1.5	0.5	1.4	0.4	0.5
21	28.0	10.9	0.1	0.3	0.3	0.5	0.4	0.5
22	2.5	3.0	0.1	0.2	0.3	0.4	0.9	0.4
23	1.3	1.7	0.1	0.2	0.2	0.4	1.3	4.0
24	1.0	1.4	0.1	0.1	0.2	0.3	44.0	21.0
25	0.7	1.2	0.1	0.1	0.1	0.3	24.0	25.7
26	0.6	1.1	0.1	0.1	0.2	0.3	28.0	34.5
27	0.5	1.0	0.4	1.5	0.4	0.2	4.4	7.3
28	0.5	0.9	0.3	1.7	0.3	0.2	2.0	3.1
29	0.5	0.8	0.3	3.8	0.2	0.1	1.5	2.1
30	0.5	0.7	0.2	1.0	0.2	0.1	1.0	1.6
31			0.2	0.2	0.2	0.1		
	53.14	177.14	10.03	89.80	109.07	113.4	135.23	209.10
Total								

Table E-2. Daily recorded and simulated suspended sediment loads for the Four Mile Creek Traer, Iowa for the 1971 water year

Date	Daily suspended sediment load in tons							
	October		November		December		January	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	1.1	1.4	4.2	3.0	3.1	3.2	2.7	1.8
2	1.5	1.3	4.0	3.0	3.1	2.9	2.4	1.6
3	1.7	1.1	3.7	2.9	3.0	2.9	1.5	1.0
4	1.7	1.0	3.4	2.8	2.6	2.6	0.8	0.6
5	1.7	1.0	3.1	2.7	2.3	2.3	1.3	1.0
6	1.5	0.9	2.9	2.7	4.7	3.0	1.6	1.3
7	1.4	0.9	2.5	2.5	4.4	2.7	1.6	1.4
8	2.8	59.7	2.3	2.5	4.1	2.7	1.6	1.4
9	420.0	389.0	9.3	14.8	3.6	2.4	1.6	1.5
10	49.0	75.5	8.0	9.0	3.4	2.7	2.1	1.5
11	22.0	20.2	6.8	5.1	3.4	3.1	2.2	1.5
12	13.0	11.4	6.3	4.1	2.9	2.5	2.4	1.5
13	11.0	8.7	5.7	3.6	2.7	2.5	2.4	1.5
14	8.8	7.0	5.6	3.7	3.0	2.6	2.3	1.5
15	7.5	6.0	5.0	3.2	3.3	2.5	2.2	1.4
16	6.9	5.5	4.9	3.2	3.0	2.4	2.1	1.4
17	6.3	5.0	4.7	3.1	2.6	2.1	2.0	1.4
18	5.8	4.5	4.4	2.9	2.4	2.2	1.9	1.4
19	5.2	4.1	4.8	3.8	2.5	1.9	1.8	1.4
20	5.2	4.1	8.3	7.6	2.9	2.0	1.7	1.3
21	4.7	3.6	6.8	5.3	2.8	2.1	1.6	1.3
22	5.3	31.0	6.2	4.6	2.7	2.1	1.5	1.3
23	5.0	15.3	6.6	5.0	2.4	1.7	1.3	1.3
24	4.2	10.5	6.0	4.5	3.6	1.8	1.2	1.3
25	3.8	5.2	5.2	4.1	3.6	1.8	1.3	1.4
26	4.0	3.8	4.1	3.2	3.3	1.8	1.9	1.2
27	5.0	4.1	3.7	3.2	3.1	1.7	1.7	1.2
28	5.1	5.5	3.2	3.1	2.9	1.7	1.6	1.2
29	4.6	3.5	2.9	3.2	2.8	1.7	1.8	1.2
30	4.6	3.4	2.9	3.2	2.9	1.8	2.5	1.1
31	4.4	3.1			2.8	1.8	2.2	1.0
Total	624.80	697.20	147.50	125.30	95.90	71.20	56.81	40.90

Table E-2 (Continued)

Date	Daily suspended sediment load in tons							
	February		March		April		May	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	2.1	1.0	117.0	78.0	6.2	4.1	1.3	4.4
2	1.9	0.9	60.0	51.0	5.4	3.6	1.1	2.1
3	1.8	0.9	36.0	33.2	5.0	3.2	1.0	1.7
4	1.8	1.0	32.0	31.7	4.8	3.2	1.2	2.0
5	1.4	0.7	33.0	46.1	4.5	3.1	1.3	1.8
6	1.8	1.1	21.0	81.4	4.4	3.0	1.2	1.7
7	1.5	0.9	24.0	17.5	4.2	3.0	1.1	1.7
8	1.4	0.9	14.0	4.7	3.7	2.7	1.0	1.6
9	1.3	0.8	11.0	3.8	3.4	2.6	0.9	1.5
10	1.3	0.8	12.0	8.1	3.5	3.0	0.8	1.4
11	1.1	0.8	110.0	87.4	5.2	4.3	0.6	1.4
12	1.1	0.7	782.0	408.1	4.7	3.6	0.7	1.4
13	1.0	0.7	2060.0	1004.4	3.6	2.7	0.9	1.4
14	1.0	0.7	1650.0	559.7	3.0	2.4	1.1	1.3
15	1.0	0.7	210.0	134.7	2.6	2.4	1.3	1.2
16	1.1	0.8	51.0	63.8	4.3	4.5	1.4	1.2
17	2.1	1.5	37.0	19.1	5.5	7.1	2.2	3.0
18	138.0	30.2	70.0	23.8	3.5	3.4	48.0	45.3
19	75.0	155.6	30.0	15.6	2.6	5.1	41.0	47.4
20	52.0	169.4	11.0	10.3	2.2	3.7	13.0	11.1
21	38.0	75.1	15.0	13.3	3.0	3.7	7.0	5.2
22	27.0	44.4	15.0	10.9	1.6	2.5	5.0	4.1
23	21.0	33.5	11.0	8.1	1.2	2.2	5.5	8.8
24	16.0	25.8	7.4	5.5	0.9	2.0	296.0	149.5
25	11.0	20.4	5.7	4.5	0.8	1.9	52.0	31.9
26	106.0	60.1	5.2	4.1	0.7	1.9	22.0	10.9
27	238.0	172.7	11.0	8.6	3.3	13.9	13.0	6.9
28	251.0	129.0	11.0	9.2	2.1	4.9	8.0	5.0
29			8.4	5.5	1.7	2.5	5.3	4.5
30			8.9	6.0	1.5	2.9	3.6	4.1
31			9.2	6.5			3.6	29.8
Total	997.64	931.10	5478.80	2764.40	99.14	108.90	542.14	395.30

Table E-2 (Continued)

Date	Daily suspended sediment load in tons							
	June		July		August		September	
	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.	Rec.	Sim.
1	126.0	510.5	1.9	4.2	0.7	1.0	0.1	0.0
2	18.0	85.4	1.2	1.5	0.9	8.6	0.1	0.0
3	10.0	15.7	1.1	1.4	0.7	1.8	0.1	0.0
4	6.7	5.3	12.0	16.3	0.7	0.6	0.3	6.7
5	4.6	3.3	2.3	15.4	0.6	0.4	1.2	11.9
6	3.5	4.8	1.1	4.4	0.6	0.4	0.7	2.0
7	27.0	9.4	1.0	3.1	0.5	0.4	0.1	0.3
8	9.5	3.8	555.0	98.3	0.5	0.4	0.2	0.2
9	6.0	3.1	25.0	8.0	0.5	0.3	0.1	6.7
10	4.4	2.8	228.0	139.4	0.4	0.3	0.1	5.3
11	3.9	3.0	38.0	91.2	0.3	0.2	0.1	0.7
12	3.4	3.9	14.0	16.8	0.4	0.2	0.1	0.0
13	62.0	22.5	8.5	8.0	0.4	0.2	0.1	0.0
14	17.0	6.3	5.8	3.5	0.3	0.2	0.1	0.0
15	12.0	3.7	4.6	2.4	0.3	0.2	0.1	0.0
16	9.6	3.0	3.7	2.0	0.3	0.1	0.0	0.0
17	8.4	2.7	3.3	1.8	0.2	0.1	0.0	0.0
18	15.0	4.8	2.8	1.6	0.2	0.1	0.0	0.1
19	9.0	3.1	2.3	1.4	0.3	1.7	0.1	2.1
20	6.3	2.4	1.8	1.3	0.3	0.7	0.1	0.7
21	5.1	2.2	1.3	1.2	0.2	0.1	0.1	0.1
22	4.4	2.1	1.0	1.1	0.2	0.1	0.1	0.1
23	4.0	1.9	1.0	9.5	0.2	0.1	0.1	0.1
24	3.7	1.7	1.2	3.4	0.3	0.2	0.1	0.0
25	3.5	1.7	1.5	1.9	0.3	0.2	0.1	1.6
26	3.4	1.7	1.5	2.0	0.2	0.1	0.1	0.9
27	2.9	1.5	1.3	1.9	0.1	0.1	0.1	0.1
28	2.6	1.4	1.0	3.5	0.1	0.0	0.1	0.0
29	2.3	1.9	0.8	1.1	0.1	0.0	0.1	0.0
30	7.5	18.1	0.8	0.7	0.1	0.0	0.1	0.0
31			0.7	0.6	0.1	0.0		
Total	401.70	733.60	925.37	448.70	10.91	19.90	4.67	39.70